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DEVELOPMENT OF CORROSION RESISTANT FASTENING SYSTEMS FOR AIRCRA--ETC(U)
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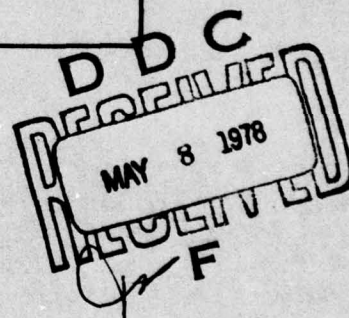
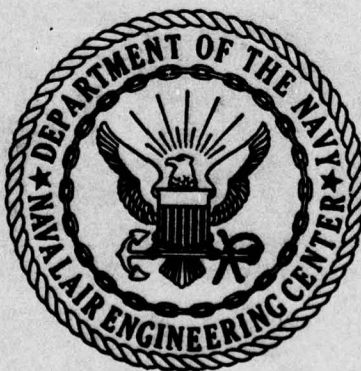
NAEC-ENG-7945

13 April 1978

FINAL REPORT

DEVELOPMENT OF CORROSION
RESISTANT FASTENING SYSTEMS FOR
AIRCRAFT CARRIER STEAM CATAPULTS

NAEC CONTRACT NOS. N68335-75-C-1323
AND N68335-76-M-3508



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NAVAL AIR ENGINEERING CENTER
LAKEHURST, NEW JERSEY 08733

ENGINEERING DEPARTMENT (SI)
CODE IDENT. NO. 80020

NAEC-ENG-7945

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I. INTRODUCTION

A study of corrosion control methods for protecting fasteners employed in aircraft carrier steam catapult systems revealed that metallic coatings of 0.5 mil thickness were inadequate, and extremely thick metallic coatings were necessary to provide superior corrosion resistance.⁽¹⁾ The additional use of inhibited polysulfide sealants in areas with temperatures less than 250°F was advocated.

A nine month exposure in a simulated service environment showed that electroplated cadmium, or electroplated zinc, overplated with cadmium, exhibited good protection in threaded areas, but not in areas exposed to the general environment. Electroplated nickel provided good protection to exposed bolt heads, but caused galvanic corrosion in threaded areas.

Therefore, a cadmium over nickel combination coating system was proposed,⁽²⁾ which would utilize the protective qualities of nickel on the head, as well as the sacrificial and lubrication properties of cadmium on the threads. This special coating system would be compared with a thick cadmium over zinc coating as well as a thick cadmium coating. The total thickness of these experimental coating systems was proposed to be 0.8 to 1.2 mils, necessitating a dimensional allowance in the bolt threads.

A mechanical program, to be conducted concurrently, was proposed⁽²⁾ for the purpose of comparing the effectiveness of the internal hexagon recess now in use, with a square or double square recess. The latter two drives should be more resistant to reaming failures, when the wrenching surface is partially corroded away.

In the launch valve area, extremely thick (0.8-1.2 mil) coating systems were proposed⁽²⁾ for studs and nuts, which clamp the steam pipe and valve flanges. Electroplated sulfamate nickel was selected as the primary choice, because of the excellent results obtained in the previous program. An extra thick coating of diffused nickel and cadmium was proposed as well as an aluminum coating system.

Finally, a comparison between thick electroplated sulfamate nickel plated MIL-S-1222 steel fasteners and Inconel 718 alloy fasteners was proposed⁽³⁾, utilizing a high temperature silicone sealant to minimize galvanic corrosion of the Metco 120 aluminum coated valve and pipe.

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II. SUMMARY

A. PROCEDURES AND RESULTS. Socket head cap screws with experimental head drive recesses were manufactured and mechanically tested to insure product integrity as well as to simulate severe corrosion. A square recess provided better mechanical properties than a double square or the standard hexagon recess.

Nine month environmental exposures of simulated track bolt joints with thick protective platings showed that a combination of nickel and cadmium was superior to only cadmium or cadmium over zinc. Polysulfide sealants provided additional protection in crevice and threaded areas.

Four and one half month environmental exposures of simulated launch valve flange joints with thick nickel plated steel fasteners or Inconel 718 alloy fasteners showed that either system is capable of resisting the severe corrodents. Disassembly was accomplished with normal human effort and no corrosion of the fasteners was observed, although the Metco 120 aluminum coating on the simulated steel flanges was attacked in all cases. A high temperature silicone sealant provided some relief from galvanic attack while an anti-seize compound caused localized attack.

B. CONCLUSIONS

1. The square recess is superior to the hexagon when drivers are worn or when corrosion causes excessive clearance.

2. A thick coating of nickel overplated with cadmium provided superior corrosion protection to track bolt heads and resesses while sacrificially protecting and lubricating the threaded and bearing areas.

3. Thick electroplated nickel (0.7 mil) over steel launch valve studs and nuts prevented their corrosion and permitted reusability of the fasteners. Corrosion resistant Inconel 718 alloy fasteners performed equally well and minimized corrosion of the aluminum coated pipe flanges.

C. PLANNED ACTION:

NAEC is conducting service trials and preparing service changes using the technology developed and reported herein.

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VII. MECHANICAL PROGRAMA. INTRODUCTION

The standard hex recess drive used in the bridle arrester track socket head cap screw tends to corrode easily and is subsequently reamed out by the wrench upon removal of the bolt. A square recess is more difficult to round out and can be driven with a conventional square drive tool used for sockets. A double-square drive (8 points) aids forging capability and could permit a smaller head diameter than with a single square recess. Both drive designs required an evaluation and comparison with the presently used hex recess.

B. SQUARE DRIVE EVALUATIONTest Parts

A quantity of socket head cap screw test pieces of each of three head drive configurations was manufactured at SPS, according to the dimensions shown in Figure 1. The screws were manufactured by standard production techniques, in order to achieve cold forging of the head and recess during normal boltmaker operation. All screws were electroplated with cyanide cadmium per Federal Specification QQ-P-416C, Class 1, Type II. Baking at 375°F for 24 hours was accomplished before application of the supplementary dichromate conversion coating. Some of the normally manufactured screws were modified to yield oversize recesses, by utilizing an Elox electrical discharge machine. Their dimensions are shown in Figure 1.

Commercially available 1/2 inch square drivers (SX2 extension bar, Snap On Tools Inc.) conforming to Federal Specification GGG-W-641D were obtained. Some were used as-received with a 30° x 0.062" chamfer. Some were machined to yield a square cut end.

Hexagon drive nibs (1/2" hex x 1 1/4" long) with square cut ends were manufactured to the material and strength requirements of Federal Specification GGG-K-275.

Tests

Five test screws of each of the three recess types having nominal size recesses were tensile tested, using the procedures and equipment described in ASTM A370. The ultimate tensile strength and mode of failure were recorded.

Five test screws of each of the three recess types having nominal size recesses were tensile-wedge tested, using the procedures and equipment described in ASTM A370. The ultimate wedge tensile strength and mode of failure were recorded.

Five test screws of each of the three recess types having nominal size recesses were fatigue tested at each of three stress levels, using the procedures and technique described in Mil-Std-1312, Test No. 11. The

screws were evaluated at stress levels of 100, 80, and 60 KSI ($R = 0.1$). The data was recorded and generated into S-N curves.

Five test screws of each of the three recess types, having nominal size recesses, were evaluated for reusability on the SPS Torque-Tension machine. The screws were lubricated with SAE 30 oil, passed through a load cell and threaded into a bushing. They were tightened to a 100,000 psi clamp load and then loosened until the load was zero. This procedure was repeated for 15 cycles and the results were recorded.

Five test screws of each of the three recess types, having various across-flat dimensions, were evaluated for ultimate torque vs. driver-recess clearance on the SPS Torque-Tension machine. The screws were lubricated with SAE 30 oil, passed through a load cell, and threaded into a heat treated (Rc 35) hex nut until torsional failure occurred, using 15 lb. end pressure on the driver. The torque at failure, the amount of driver-recess clearance and the mode of failure were recorded.

Test screws, of each of the three recess types, having two different driver-recess clearance dimensions, were evaluated for torque vs. driver engagement on the SPS Torque-Tension machine. Clearances were selected which represented brand new screws (.002") as well as the minimum degree of corrosion at which the hexagon recess would sustain a reaming failure (.025"). The screws were lubricated with SAE 30 oil, passed through a load cell and threaded into a heat treated (Rc 35) hex nut. A hardened spacer (Rc 35) was inserted in the screw recess to decrease engagement of the driver. The screw was tightened until torsional failure occurred, using 15 lb. end pressure on the driver. The torque at failure, the load at failure, the reduction in engagement and the mode of failure were recorded.

Torque-Tension relationships generated during the torque vs. driver recess clearance tests were plotted.

C. RESULTS

The ultimate tensile strength of the screws is shown in Table I. All three head drive configurations produce approximately the same values, indicating no detrimental effect of the square or double square recesses.

When a 6° wedge was placed under the head for tensile testing, the results were so close that no significant effect of the square or double square was observed, as shown in Table II.

Fatigue life was equivalent at each of three stress levels for the three head configurations. The raw data is shown in Table III and is plotted as an S-N curve in Figure 2.

Reusability was good for all three drives for 15 applications, as shown in Table IV.

Evaluation of the ultimate torque, achieved as a function of the driver-recess clearance, showed that the square drive was most resistant to

failure, as shown in Table V. The hexagon drive failed in the recess at 0.025" clearance, the double square failed in the recess at 0.035" clearance, but the square did not fail in the recess until 0.045" clearance was reached.

Evaluation of the ultimate torque, achieved as a function of the driver engagement, (with 0.002" driver-recess clearance), showed that the square drive was significantly better than the hexagon or double square drives, for engagements up to 0.100 inches. At 0.175" through the full engagement of 0.225 inch, no difference in performance was noted, as shown in Table VI and Figure 3.

When the driver-recess clearance was increased to 0.025", the square drive again exhibited the best performance, for engagements up to 0.100 inch, followed by the double square and then the hexagon. At full engagement, there was no difference between the three drives, as shown in Table VII and Figure 4.

Figure 5 shows the torque-tension relationship obtained during the torque test procedures.

D. DISCUSSION

The mechanical test program conducted shows that square and double square recess drives are comparable to the normally used hexagon recess, with respect to overall screw strength, as measured by direct tension, fatigue and reusability.

The ability of all the recesses to resist reaming or tearing was apparent at full engagement of the driver, but more damage was done as driver-recess clearance increased and as driver engagement decreased.

The significance of this data lies in the fact that the recess sides will corrode away while foreign debris covers the recess bottom. Thus, after some time, a greater clearance between recess and driver will exist, and engagement of the driver in the recess will be less than 100%. With this in mind, the data in Figure 4 indicates the square drive to be the most effective.

If corrosion causes the driver recess clearance to exceed 0.020", the hexagon recess screw will ream out, according to the data in Table V. The square drive would still be effective to at least 0.040" clearance, which translates to double the exposure time provided by the hexagon recess. The double square recess does not ream out until more than 0.030" clearance is reached, thus affording 50% more exposure life than the hexagon recess. However, the double square recess is not as resistant to failure as the square recess at the two clearances evaluated, if less than half engagement of the driver is employed.

Wear of the drivers was not evaluated, but it would be obvious that rounded or flattened corners are more detrimental to the hexagon than to the square, thus affording the latter drive system an advantage where tool abuse, wear, and corrosion of all surfaces is a normal occurrence.

The data shows that, at full engagement (an ideal condition), hardly any difference exists between the three drive systems. In view of the torque requirements normally employed, compared to those measured in this test program, it seems that the hexagon recess now in service should be satisfactory. The fact that it is not suggests the cause as undefined conditions in the tapped hole, the degree of lubricity present, the amount of driver wear, misalignment during tightening, debris in the drive recess, or corrosion.

As a laboratory exercise, the square drive recess is superior and is recommended for testing on an active aircraft carrier. According to the terms of the proposal for this contract, ⁽²⁾ 2000 screws were manufactured, according to Navy-supplied overall dimensions, as shown in Figure 6. The head drive recess recommended by SPS is the square, which was employed for the experimental lot, per NAEC written approval.

E. CONCLUSIONS

1. The square recess resists reaming and tearing better than the double square or the hexagon, when excessive clearance is a result of corrosion or wear.
2. The square recess is at an advantage when drivers have rounded or flattened corners.
3. The presence of the square recess does not adversely affect mechanical properties of the screw.

VIII. CORROSION PROGRAMA. INTRODUCTION

It is well known that thicker cadmium plating generally provides much more protection to bolts which more than offsets the slight additional cost. Combinations of coatings have been shown to provide protection which is better than that obtained from the individual coatings.⁽¹⁾ Even so, the use of polysulfide sealants in combination with sacrificial coatings provides superior protection of bridle arrester track bolts.⁽¹⁾

The sealant cannot be used on the bolt head and cadmium or zinc coatings generally do not provide adequate protection to the head and drive recess because of their inability to resist corrosion from the environment. Therefore, nickel coatings may be a better choice over which a sacrificial coating is employed. The nickel is not desirable on the bolt threads, whereas cadmium is because it serves as a lubricant.

The work done previously⁽¹⁾ showed a combination of zinc and cadmium provided excellent protection, but little is known about the optimum ratio of coating thickness.

Below deck, alloy steel studs and nuts have been coated with various systems which are resistant to corrosion but not enough for the severity encountered in this application. The use of a corrosion resistant alloy solves the problem of reusing the hardware but adds considerably to the initial cost. Coatings of greater thickness provide increased protection at minimal initial expense but are really only buying time until failure.

Coatings which have barrier qualities and are on the order of 1 mil in thickness are candidate materials providing they can withstand 700°F and are resistant to corrosion by the chemical environment found in the launch valve room.

No matter which system is used for preventing stud and nut corrosion, galvanic attack of the Metco 120 aluminum coating on the launch valves and pipes is expected from the noble metal alloy or coated studs and nuts. Therefore, a high temperature sealant could be used to provide an insulative barrier between the incompatible materials.

B. LOW TEMPERATURE PROCEDURE

Socket head cap screw blanks were cut, thread rolled and heat treated to provide a quantity of 3/4-10 x 1 1/4 fasteners, with a plating allowance of 0.8 to 1.2 mil. These were mechanically cleaned by dry blasting with 150 grit aluminum oxide, and were then electroplated with one of the three systems shown in Table VIII.

All screws were baked at 375°F for 24 hours prior to applying the conversion coating.

Test blocks were machined from 4340 steel, manganese bronze, and HY80 steel, according to the dimensions shown in Figure 7. These were deeply stamped for identification and were thoroughly vapor degreased in trichlorethylene.]

The screws having coating systems without any additional lubricant or treatment were installed in the left hand holes of the test blocks while freshly prepared polysulfide sealant (PR 1436-G Sprayable) was applied to the threads and underhead of the coated fasteners destined for the right hand holes.

The screws were tightened in the test blocks to a seating torque of 150 foot pounds.

These assemblies were allowed to cure at room temperature for 24 hours, before being packaged for shipment to the laboratory of the Ocean City Research Corporation for a nine month exposure.

The exposure was conducted on a turntable with programmed heat and corrosion sources according to the schedule shown in Table IX. After three months of exposure, the test blocks were taken off the turntable and one screw of each different coating system condition was removed while measuring the breakaway and prevailing torques.

The screws were cleaned with soap and water and solvent (1:1 MEK/Toluene) in order to remove corrosion products and cured sealant. A brass bristle brush and a motor mounted wire wheel were employed to aid in the cleaning without removing the metallic protective coating.

After examination of the screws and the test block holes (these were superficially cleaned of loose debris), the screws were reinstalled in the same manner as when they were new. Bare screws were installed on the left and polysulfide sealant (freshly prepared) was applied to those installed on the right hand side of the blocks. As before, all screws were tightened to 150 foot pounds of torque. The assembled test blocks were exposed almost immediately to the cyclic test conditions on the turntable.

After an additional three months of exposure, the test blocks were taken off the turntable and the screws removed were the same as from the initial three month evaluation. Torque measurements, cleaning, examination and reinstallation were accomplished just as before. The assembled test blocks were allowed to remain indoors for 48 hours so the sealant would fully cure before being exposed to the cyclic conditions on the turntable for a final three months.

After nine months of exposure, the test blocks were returned to SPS where they were disassembled and cleaned. Breakaway and prevailing torque measurements were made for every screw. Before cleaning them by scrubbing with soap and water, mild brushing with a brass bristle brush and very careful dry blasting with glass beads was accomplished to remove accumulated corrosive products in the head recess. The sealant was softened by immersion overnight in a mixture of MEK/MIBK solvents, and was then removed by careful burnishing with a wire wheel. The steel blocks were dry blasted with 150 grit aluminum oxide to remove rust but the manganese bronze blocks were cleaned by swabbing them with diluted hydrochloric acid. The cleaned parts were carefully observed with the aid of a stereozoom microscope.

C. HIGH TEMPERATURE PROCEDURE

Studs were manufactured from alloy steel conforming to MIL-S-1222, Type I (B5F5 used), and according to the dimensions shown in Figure 8. These were heat treated to a minimum hardness of Rc 36 before rolling threads with an allowance for a thick plating system. Mating nuts were provided by NAEC from the Federal Stock System (MS 16286-8) and were tapped out to allow a 1 mil thick plating system.

Three different plating systems were applied, all having a total thickness of 0.8 to 1.2 mils. After mechanical cleaning by means of 150 grit aluminum oxide, the studs and nuts were coated with one of the three systems shown in Table X.

All threaded and bearing surfaces were brush coated with Sandstrom 9A, an inhibited lubricant containing molybdenum disulfide. Curing was accomplished at 400°F for 1 hour.

The test blocks for the studs and nuts were made from 4130 steel according to the dimensions shown in Figure 9. They were deeply stamped for identification, thoroughly vapor degreased in trichlorethylene and shipped to NAEC for coating with the Metco 120 aluminum system. The coated test blocks were returned to SPS and clamped together by means of the studs and nuts. A gasket (Flexitallic CG-1B) separated the two clamped plates. Tightening was stopped when the gasket was completely compressed. The tightened assemblies were carefully packed and shipped to Ocean City Research Corp. for a nine month exposure test.

The test blocks were encapsulated in cocoons of lagging material and exposed at elevated temperature to a mixture of corrodents by periodic injection as shown in Table XI. After approximately 4 1/2 months of this exposure treatment, the cocoons were opened and the assemblies were inspected.

Efforts to remove studs and nuts from the blocks were initially unsuccessful because of the extensive corrosion present. The blocks were transported to the SPS laboratory where a high capacity torque machine was able to untorque the nuts (measurement unavailable) and a Universal (tensile) testing machine was used to push the studs out of the holes (up to 25,000 lb. used). The remaining nuts on the studs were removed only after excessive force with a large vise and pipe wrench were employed.

Conventional cleanup procedures using soap and water, wire wheel and hand brushes were used, in order to determine the degree of coating protection remaining. These specimens were not exposed for the additional 4 1/2 months.

An additional 4 1/2 month exposure was initiated using the following materials:

1. Four alloy steel (MIL-S-1222, Type I, B5F5 used) studs were manufactured conforming to the dimensions shown in Figure 8. These were heat treated to a minimum hardness of Rc 36 before rolling

threads with an allowance for a thick plating system. They were electroplated with sulfamate nickel to a thickness of 0.7 mil, baked at 375°F for 23 hours and then coated with MIL-L-8937 inhibited dry film lubricant on the threads only.

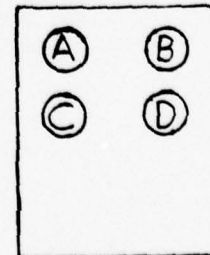
2. Four new alloy steel studs (same manufacturing procedure as above) were electroplated with sulfamate nickel to a thickness of 1.0 mil, baked, and coated with dry film lubricant on the threads.
3. Four new Inconel 718 studs were manufactured according to Figure 8 and four previously used Inconel 718 studs were refurbished by glass bead blasting. All were coated on the threads with dry film lubricant as described above.
4. Eight new alloy steel (MIL-S-1222, Navy supplied) hex nuts were tapped to allow coating with 0.7 mil electroplated sulfamate nickel. These were baked for 23 hours and coated all over with the inhibited dry film lubricant.
5. Eight new alloy steel (MIL-S-1222, Navy supplied) hex nuts were tapped to allow coating with 1.0 mil electroplated sulfamate nickel. These were baked for 23 hours and coated all over with the inhibited dry film lubricant.
6. Eight Waspaloy hex nuts previously used, were cleaned by glass bead blasting. Eight new Inconel 718 12 pt. nuts were glass bead blasted. All were coated with MIL-L-8937.
7. Four sets of simulated pipe flange joints from previously used experimental specimens were remanufactured according to Figure 9. These were coated with the Metco 120 aluminum system by NAEC.
8. Each stud hole in the simulated pipe flange joint was thoroughly cleaned and smoothed and the diameters carefully measured.
9. A new Flexitallic gasket was installed in each joint.
10. The following placement in each joint was followed:

Joint One

Position A	Alloy steel, 0.7 mil Ni
Position B	Alloy steel, 1.0 mil Ni
Position C	Alloy steel, 0.7 mil Ni
Position D	Alloy steel, 1.0 mil Ni

Joint Two

Position A	Alloy steel, 0.7 mil Ni +
Position B	Alloy steel, 1.0 mil Ni +
Position C	Alloy steel, 0.7 mil Ni +
Position D	Alloy steel, 1.0 mil Ni +



G.E. silicone sealant
TBS757A applied liber-
ally to all stud and
nut areas

Joint Three

Position A	Inconel 718, no sealant
Position B	Inconel 718, + sealant TBS757A
Position C	Inconel 718, no sealant
Position D	Inconel 718, + sealant TBS757A

Joint Four

Position A	Inconel 718 + SermeTel 385 on bearing areas
Position B	Inconel 718 + Never-Seez on bearing areas
Position C	Inconel 718 + SermeTel 385 on bearing areas
Position D	Inconel 718 + Never-Seez on bearing areas

11. All nuts were torqued until the Flexitallic gaskets were completely compressed.
12. The four joints were shipped to Ocean City Research Corp. for the 4 1/2 month exposure as described previously in this report.

The text blocks were encapsulated and exposed for 4 1/2 months as described previously. The cocoons were opened and the assemblies were thoroughly brushed off and photographed.

Efforts to disassemble the fasteners were relatively easy and accomplished by one person using a maximum breakaway torque of 200 ft. lb. The joints required from 25 to 150 ft. lb. to first loosen the nut and then only a minimal effort to remove it. Cleanup with soap and water, wire wheel and hand brush was followed by glass bead blasting at low pressure to remove all loosely adherent corrosion products before final photography and hole diameter measurement.

D. RESULTS:

1. Low Temperature

Tables XII through XVII show the location of the removed screws and list the observations made concerning the various areas of the specimens. The observations after 3 and 6 month exposures were made after superficial cleaning had been done, whereas those after the full 9 month exposure are indicative of well cleaned surfaces. Photos 1-12 provide additional observations.

A study of this data shows the cadmium and zinc coatings exposed to the outside environment were completely consumed with resultant rusting of the head and recess. The nickel coating remained intact on the screw, except for the recess bottom in most cases, and provided continued rust free protection.

The cadmium coating was present on most of the threaded area, the fillet and underhead in practically all of the specimens, showing that penetration of the corrodent past the head was negligible. The

screw point was corroded in all instances except for the nickel plating, because of the presence of corrodent at the open bottom of the specimen blocks.

The breakaway and prevailing torques do not seem meaningful until the 9 month data is studied. The sealant is then seen to provide lower breakaway values than for no sealant, and fairly consistent prevailing torques. Examination of the threaded holes showed less corrosion and damage to the threaded holes when sealant was employed.

2. High Temperature

Examination of the first 4 1/2 month exposure of studs and nuts revealed extensive corrosion on threaded surfaces as well as severe corrosion of the Metco 120 aluminum coating on the block as indicated in Table XVIII. The "welding" action of the corrosion products seemed sufficient to effectively resist disassembly of the joint.

So little of the coatings remained that it was impossible to compare their relative protective qualities. All three coating systems were considered to have failed because of their inability to allow disassembly. The protection afforded by the Metco 120 system was questionable in view of the almost complete absence of the coating around the fasteners no matter which of the three fastener coating systems was employed.

Examination of the second 4 1/2 month exposure of studs and nuts provided a wealth of new information and confirmation of previous successful trials, as condensed in Table XIX and shown in Photos 17-24.

No corrosion was evident on any of the studs or nuts whether they were .7 mil nickel plated, 1.0 mil nickel plated or Inconel 718. The absence of corrosion in the threads, rather than the presence of a lubricant or sealant in the threads was the primary cause for easy disassembly, as evidenced by the properties of the nickel plated and Inconel 718 specimens with no sealants, sacrificial coatings or anti-seize compounds.

The presence of an additional compound in the threads did not offer corrosion protection to the fastener, as described above, but did seem to affect the steel block and the Metco 120 aluminum coating system. When no additional compounds were employed on the nickel coated fasteners, the steel block was completely devoid of protective coating, except for a small amount at the far end. This was probably due to galvanic corrosion between the nickel and the aluminum.

When the same nickel plated fasteners were overcoated with TBS757A, a high temperature silicone sealant, considerably more of the Metco aluminum coating remained on the steel blocks. However, when Inconel 718 fasteners were used with and without the high temperature sealant, even more of the Metco 120 coating was present. The latter evidence suggests a much lower galvanic current between Inconel 718 and aluminum than between nickel plated steel and aluminum.

The presence of an antisieze compound caused the extensive loss of the Metco aluminum coating on the fourth block and the localized galvanic attack around the nuts. The presence of SermeTel 385 on the other two Inconel 718 nuts prevented localized attack but could not prevent the loss of the aluminum coating.

Measurement of the flange block hole diameters before and after the exposure revealed little or no change due to galvanic corrosion between the more noble nickel coating or Inconel 718 alloy and the less noble steel block. The data is shown in Table XX.

E. DISCUSSION:

The low temperature application results after nine months proved nickel is an effective barrier to the direct deck environment but cadmium and zinc are not. It also showed that a fairly thick coating (1.0 mil) was able to function adequately with respect to mechanical parameters. The action of the sealant in reducing or preventing the penetration of corrosive into the threaded area was beneficial. As a side effect, the loosening process was controlled better with sealant, with lower breakaway torques and more consistent prevailing torques.

The high temperature application results after the first 4 1/2 months were not only disappointing, but also inconsistent with previous successful results. The intensity of corrosion attack was much greater than in the previous study,⁽¹⁾ even though the exposure conditions were exactly the same. The coatings on the fasteners were thicker than before and should have lasted longer. The Metco 120 system was applied the same as before and should not have suffered the severe degradation.

After consultation with NAEC and Ocean City Research personnel, it was decided to revise the remainder of the test program concerning the high temperature exposure according to a new proposal.⁽³⁾

The second high temperature results were successful, because they proved the corrosion resistance of thick nickel coatings and the superior galvanic compatibility of Inconel 718 with the Metco 120 aluminum coating. A high temperature silicone sealant was shown to be beneficial, an antisieze compound was shown to be detrimental, and a sacrificial coating proved to have little or no value in this hostile environment.

F. CONCLUSIONS:

Low Temperature

1. Electroplated sulfamate nickel (0.4-0.6 mil) is an effective barrier to the direct deck environment.
2. Cadmium and zinc (0.8-1.2 mil) are not effective barriers to the direct deck environment.
3. The combination of nickel (0.4-0.6 mil) overplated with cadmium provided lubrication and sacrificial protection in bearing areas without total consumption of the cadmium.

4. A polysulfide sealant provided lower breakaway torques in all cases thus making it easier for fastener removal.
5. All three coating systems provided protection to the fastener on engaged areas, but only the nickel (remaining) provided protection to exposed fasteners.

High Temperature

1. The initial high temperature test results were inconsistent with previous results.
2. Electroplated nickel is protective to steel when plated to 0.7 or 1.0 mil thickness.
3. Inconel 718 is more galvanically compatible with the Metco 120 aluminum coating than electroplated nickel.
4. A high temperature silicone sealant aids the electroplated nickel - Metco 120 coating compatibility.
5. Never-Seez produced localized galvanic attack.
6. SermeTel 385 did not provide significant corrosion protection.

IX. REFERENCES

- (1) E. Taylor and M. Buppert, Final Report "The Corrosion Control of Fastening Systems for Aircraft Carrier Steam Catapults". NAEC-ENG-7868, 31 Mar. 1976.
- (2) Standard Pressed Steel Co. Technical Proposal No. 51, "Development of Corrosion Resistant Fastening Systems for Aircraft Carrier Steam Catapults".
- (3) Standard Pressed Steel Co. Technical Proposal No. 59 Revised, "Evaluation of Corrosion Protection Systems for Launch Valve Studs and Nuts".



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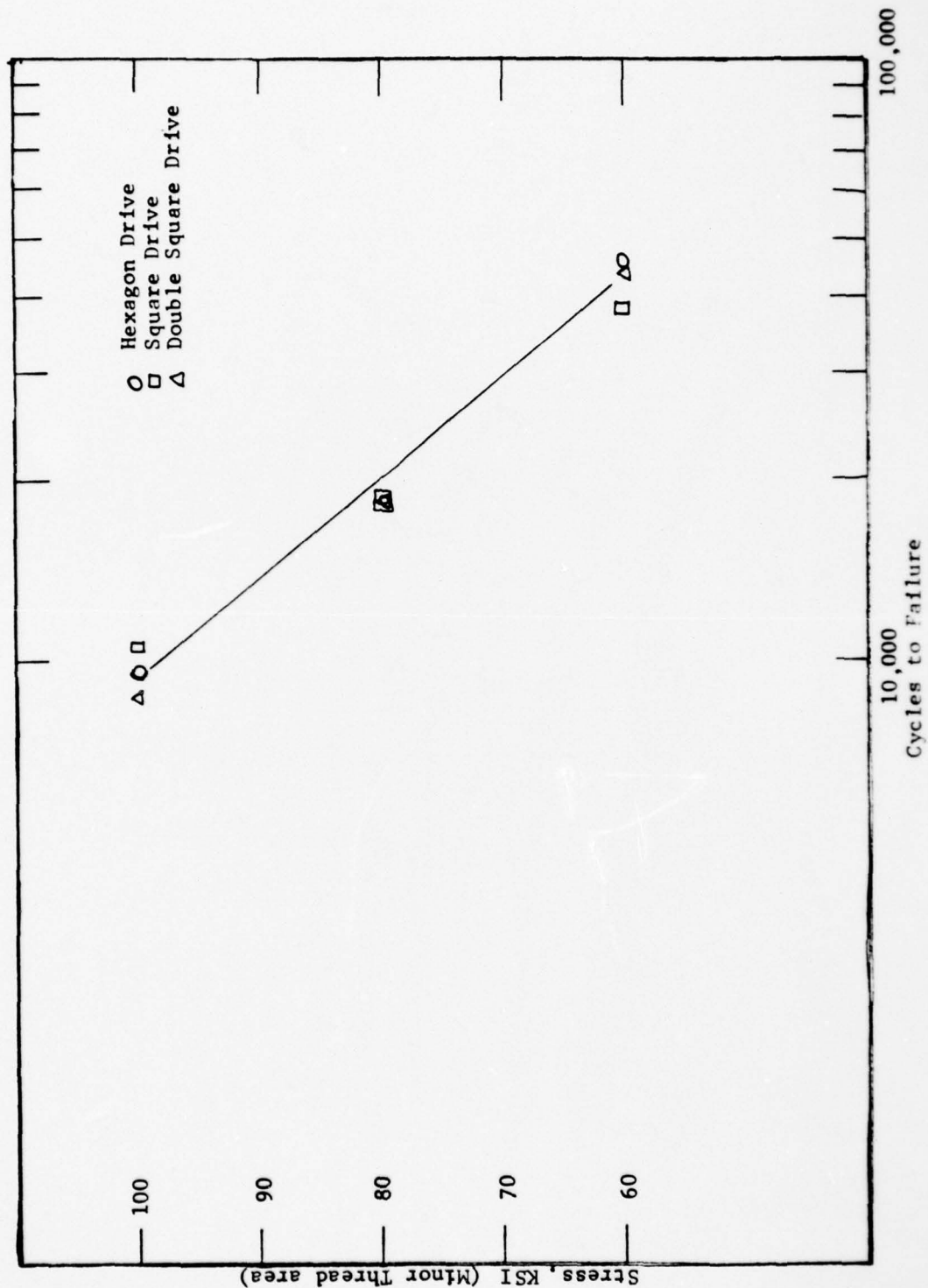


Figure 2. Fatigue life of 5/8" - 11 Socket Head Cap Screw Test Parts
R = 0.1

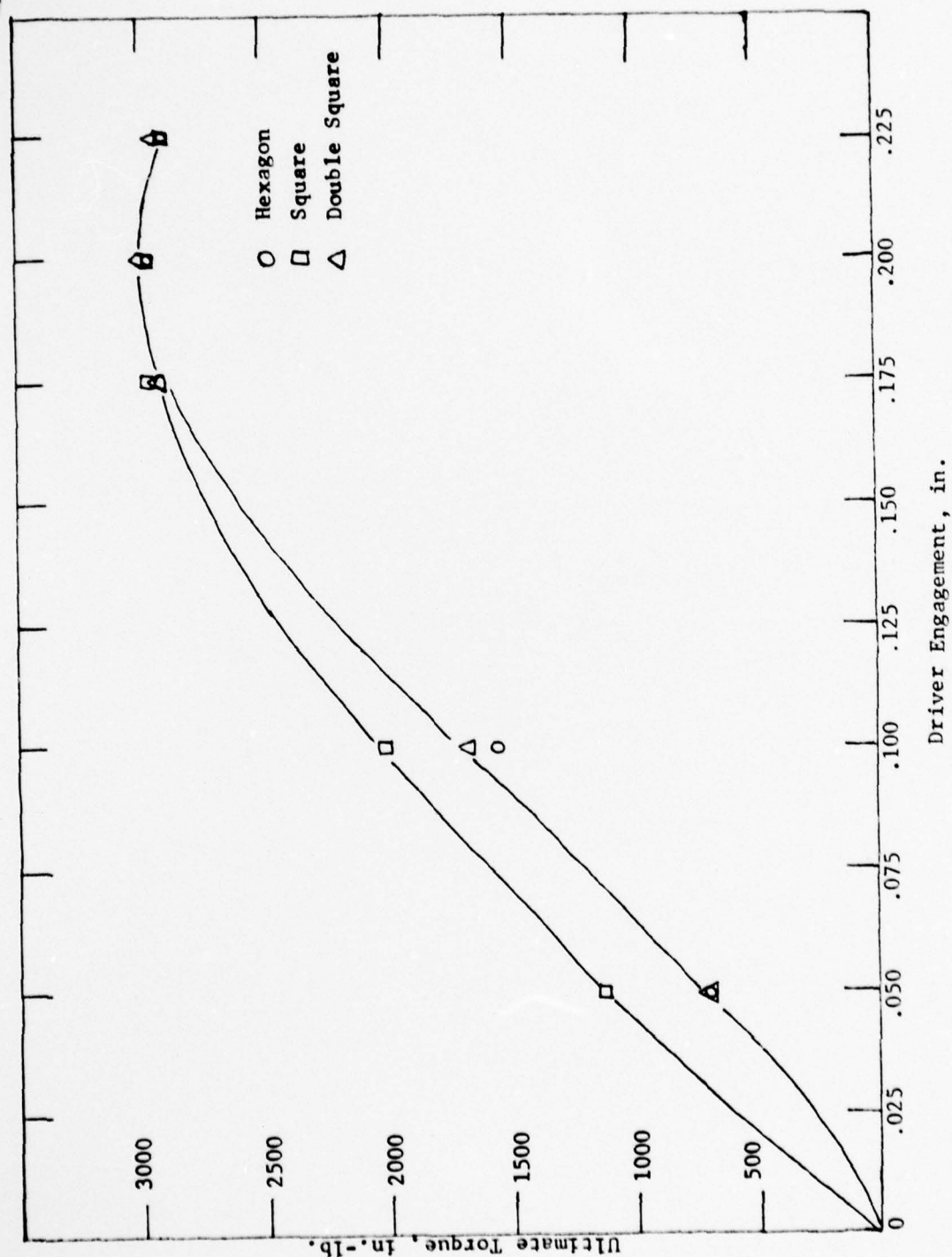


Figure 3. Ultimate Torque vs. Driver Engagement for 5/8" - 11 SHCS Test Parts (.002" Driver-Recess Clearance) (SAE 30 oil used)

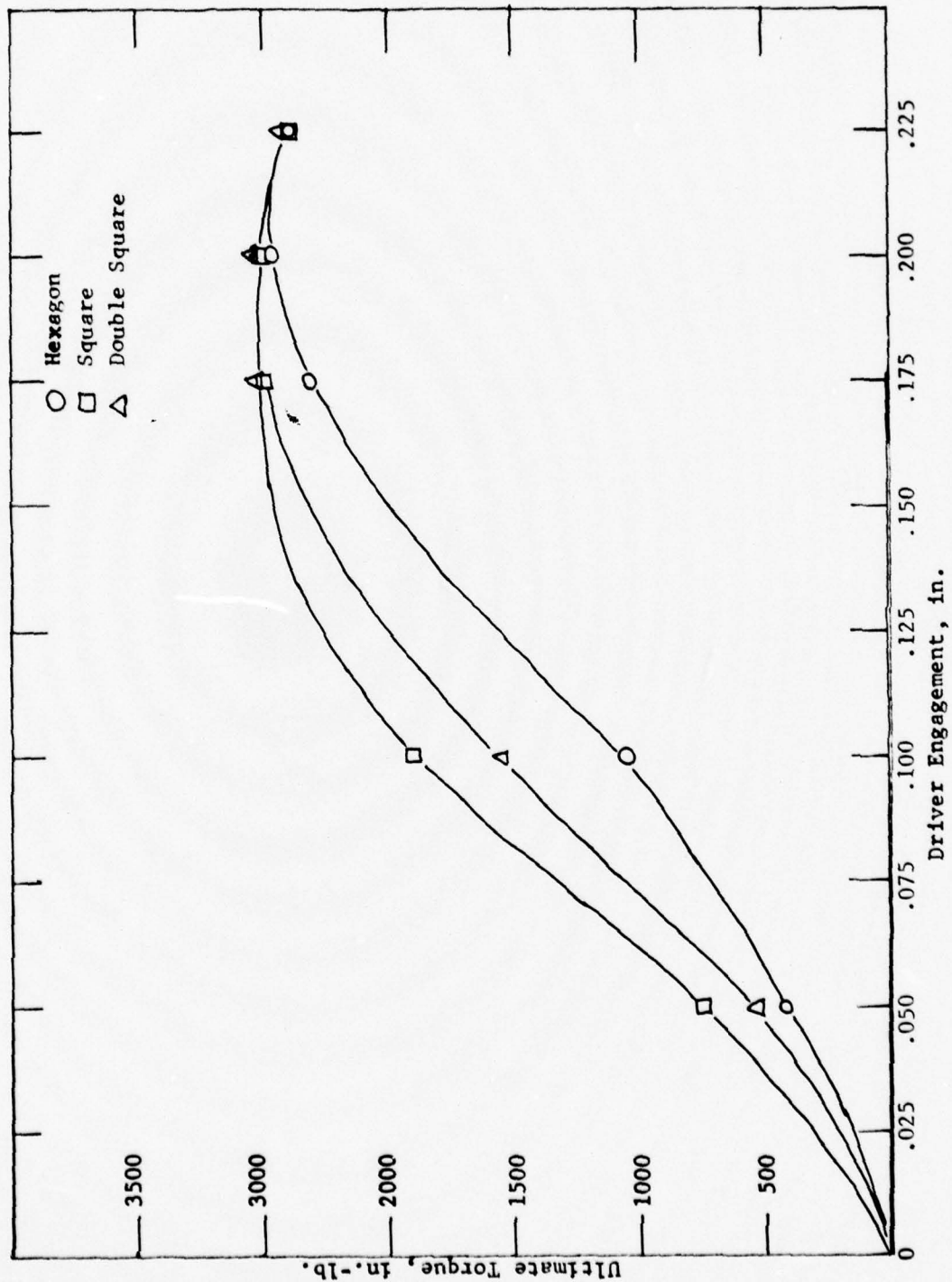


Figure 4. Ultimate Torque vs. Driver Engagement for 5/8" - 11 SHCS Test Parts (.025" Driver-Recess clearance) (SAE 30 oil used)

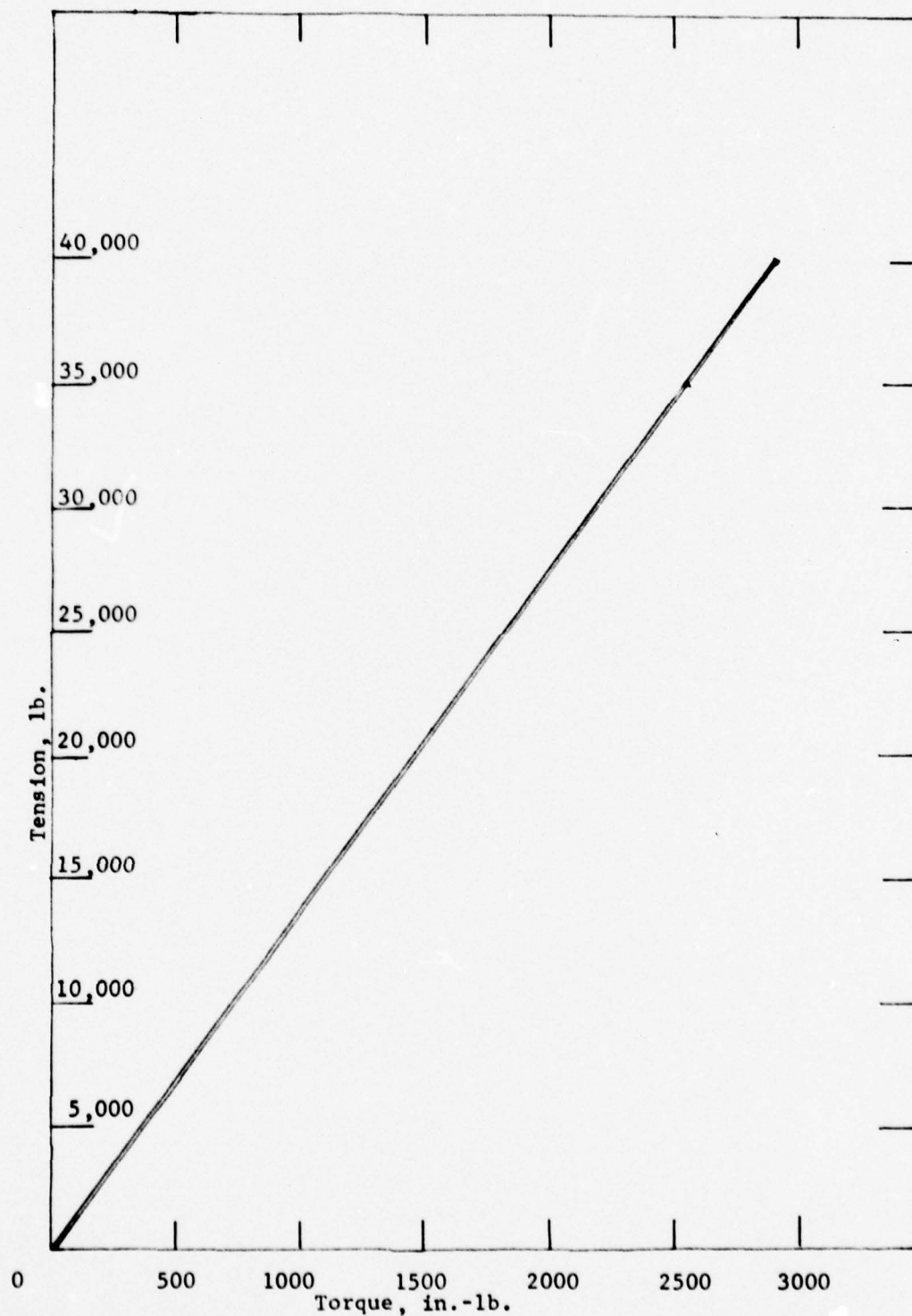


Figure 5. Torque-Tension Relationship of 5/8"-11 SHCS Test Parts
(SAE 30 oil used)

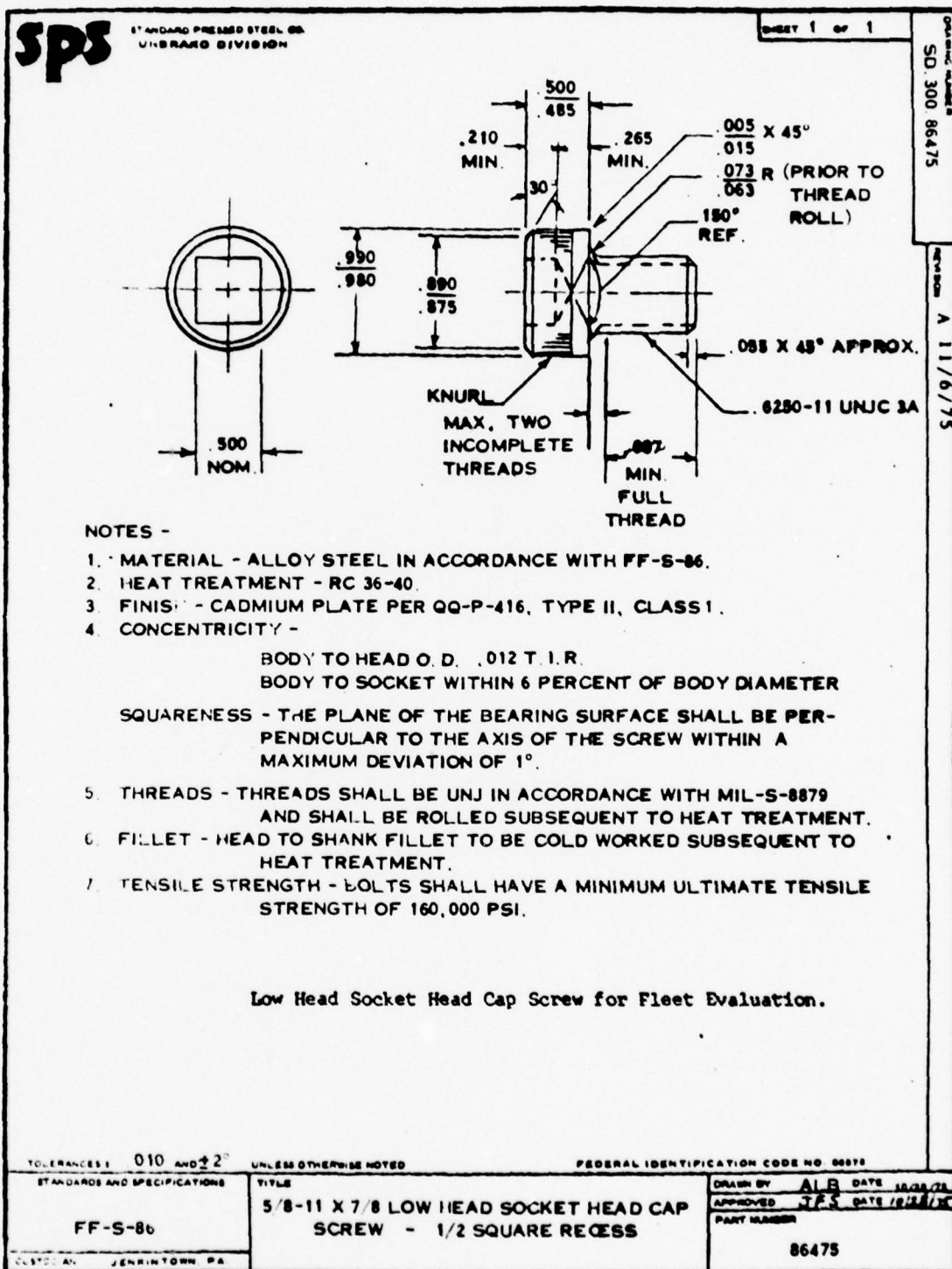


Figure 6.

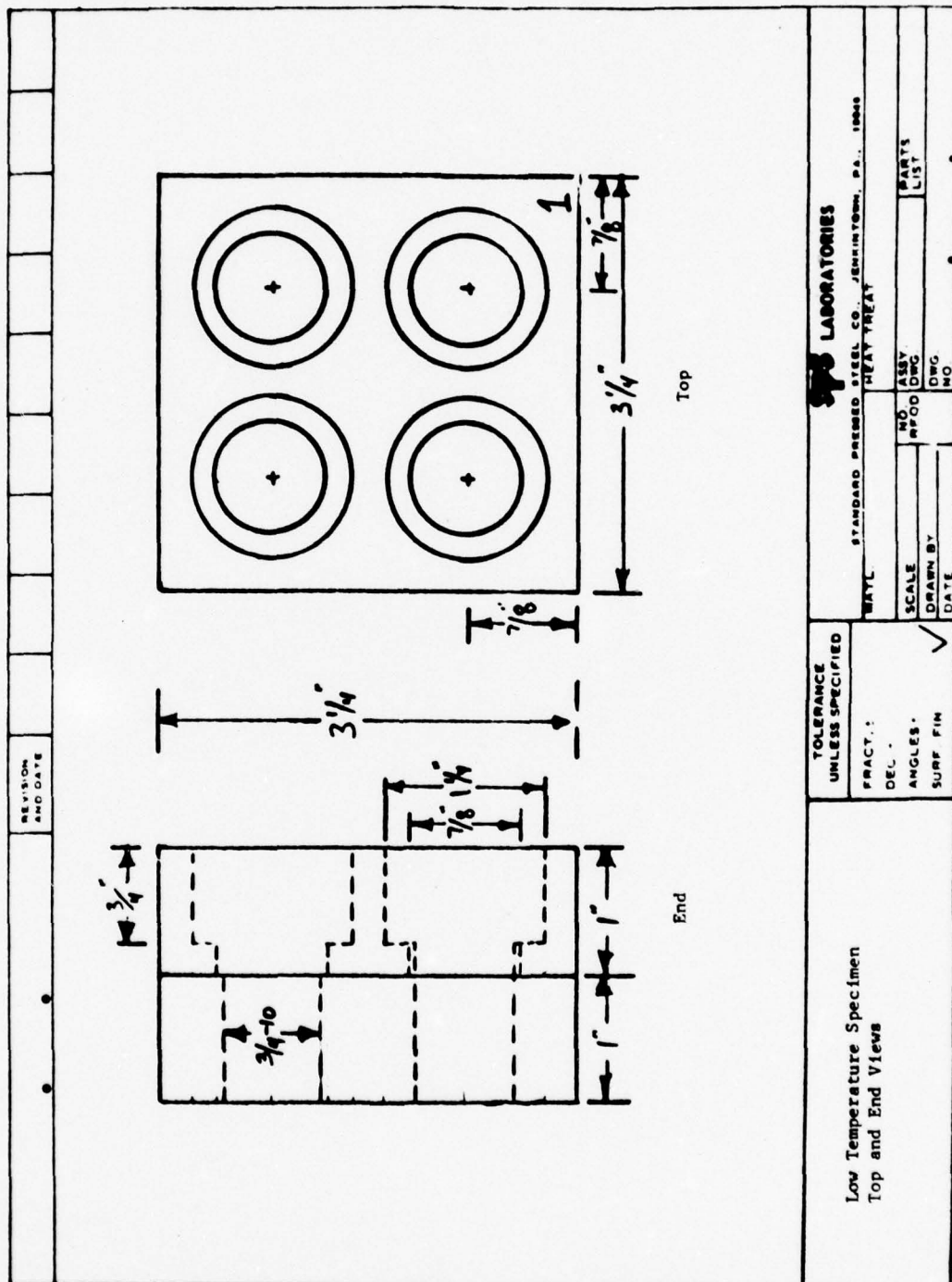
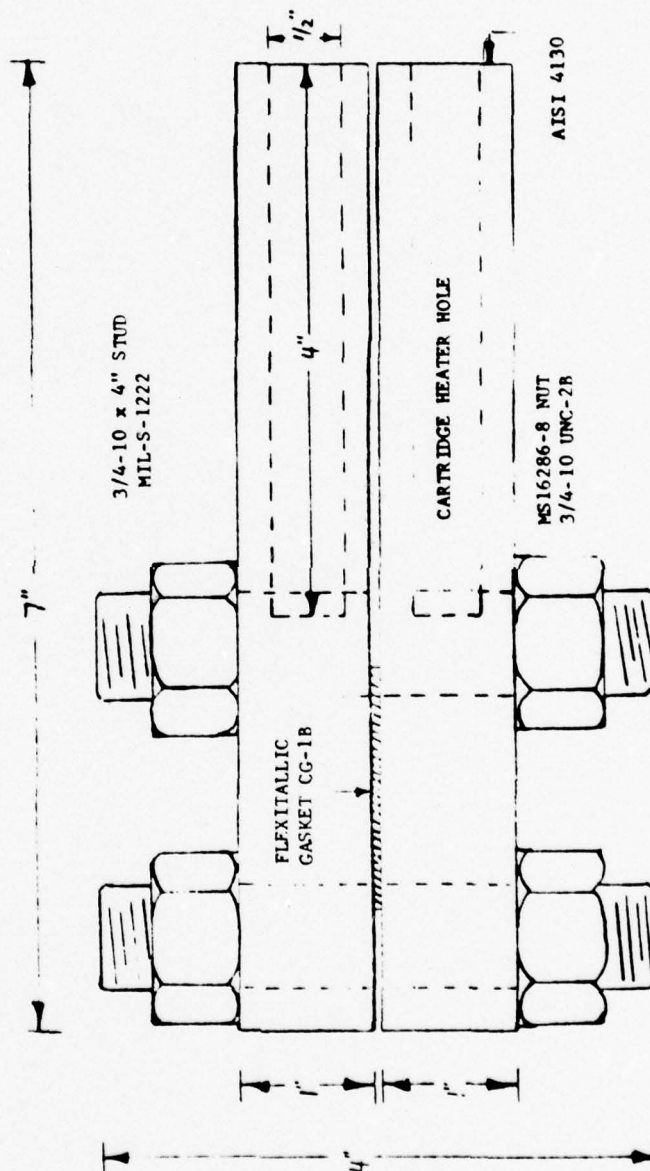


Figure 7.



High Temperature Specimen

Figure 9a.

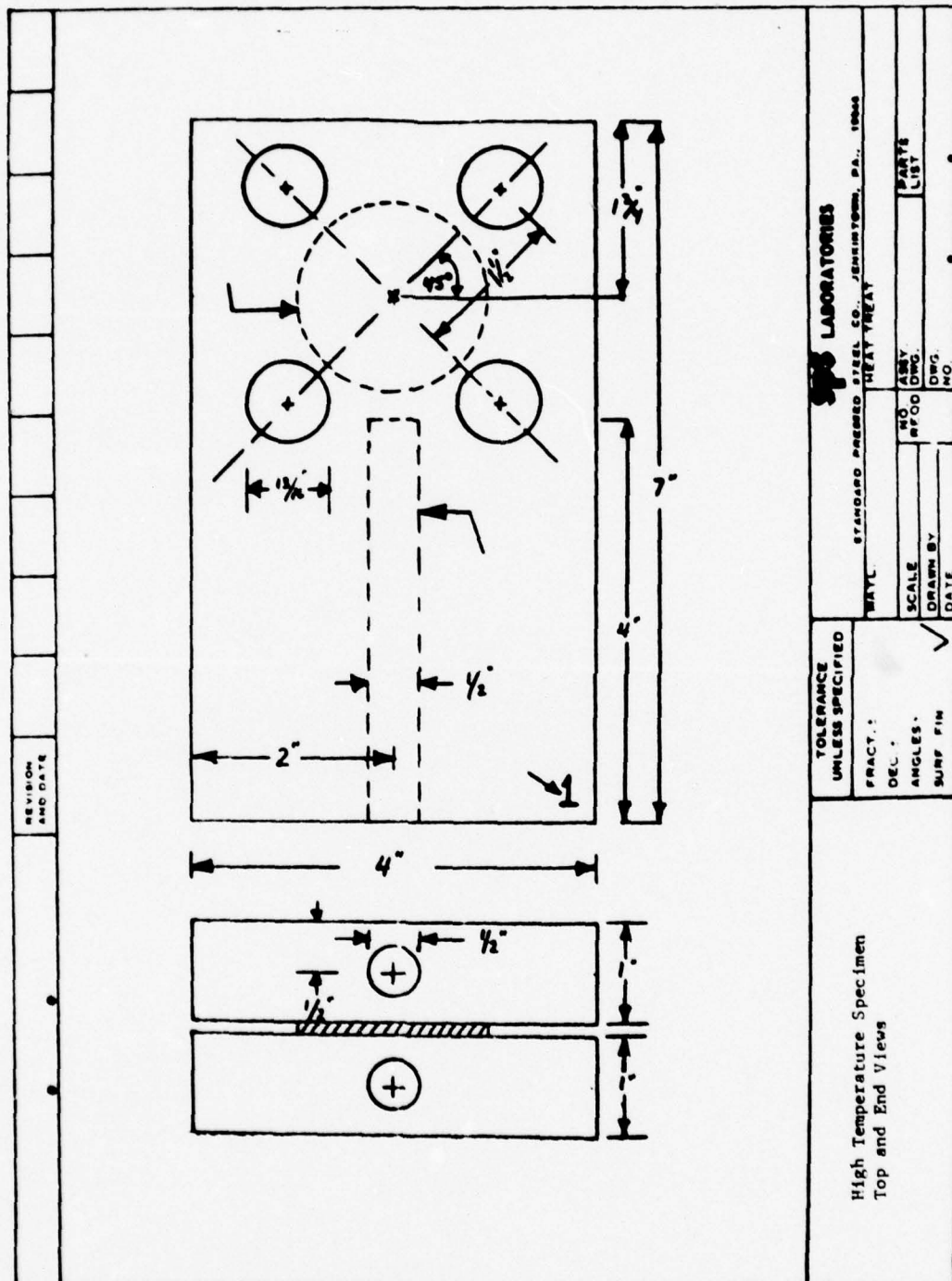


Figure 9b.

TABLE I

Ultimate Tensile Strength
of 5/8" - 11 Socket Head Cap Screw Test Parts

No.	Recess	Load, lb.	Load, psi*	Failure Mode
1	Hexagon	42,400	187,600	Thread
2	"	43,000	190,260	"
3	"	42,500	188,050	"
4	"	42,300	187,170	"
5	"	42,000	185,840	"
		Av. 42,440 ± 365	187,784 ± 1,612	
1	Square	41,900	185,400	Thread
2	"	41,500	183,630	"
3	"	41,500	183,630	"
4	"	41,500	183,630	"
5	"	42,000	185,840	"
		Av. 41,680 ± 249	184,426 ± 1101	
1	Double Square	41,900	185,400	Thread
2	"	41,400	183,190	"
3	"	41,300	182,745	"
4	"	42,000	185,840	"
5	"	41,600	184,070	"
		Av. 41,640 ± 305	184,249 ± 1348	

Note* Based on tensile stress area of 0.2260 sq. in. one standard deviation, σ used.

TABLE II

6° Wedge - Ultimate Tensile Strength
of 5/8" - 11 Socket Head Cap Screw Test Parts

No.	<u>Recess</u>	<u>Load, lb.</u>	<u>Load, psi*</u>	<u>Failure Mode</u>
1	Hexagon	42,100	186,280	Thread
2	"	42,000	185,840	"
3	"	42,100	186,280	"
4	"	42,000	185,840	"
5	"	42,000	185,840	"
		Av. 42,040 ± 55	186,016 ± 241	
1	Square	42,000	185,840	Thread
2	"	42,100	186,280	"
3	"	42,000	185,840	"
4	"	42,000	185,840	"
5	"	42,300	187,170	"
		Av. 42,080 ± 130	186,194 ± 578	
1	Double Square	41,000	181,400	Thread
2	"	40,200	180,090	"
3	"	41,000	181,400	"
4	"	41,500	183,630	"
5	"	41,000	181,400	"
		Av. 40,940 ± 467	181,584 ± 1277	

Note * Based on tensile stress area of 0.2260 sq. in.
Average load shows one standard deviation, σ .

TABLE III

Fatigue Life
of 5/8" - 11 Socket Head Cap Screw Test Parts

No.	Recess	Cycles to Failure at Stress Level, KSI			Failure Mode
		100'	80	60	
1	Hexagon	11,000	17,000	44,000	Thread
2	"	9,000	20,000	43,000	"
3	"	9,000	18,000	44,000	"
4	"	10,000	17,000	43,000	"
5	"	9,000	20,000	40,000	"
		Av. 9,600	18,400	42,800	
	Log Mean Av.	9,568	18,350	42,774	
1	Square	10,000	19,000	42,000	Thread
2	"	11,000	18,000	39,000	"
3	"	12,000	20,000	40,000	"
4	"	11,000	19,000	43,000	"
5	"	9,000	16,000	29,000	"
		Av. 10,600	18,400	38,600	
	Log Mean Av.	10,549	18,347	38,233	
1	Double Square	8,000	16,000	39,000	Thread
2	"	10,000	17,000	43,000	"
3	"	9,000	17,000	46,000	"
4	"	9,000	23,000	45,000	"
5	"	8,000	18,000	44,000	"
		Av. 8,800	18,200	43,400	
	Log Mean Av.	8,768	18,046	43,300	

TABLE IV
Reusability
of 5/8" - 11 Socket Head Cap Screw Test Parts

<u>No.</u>	<u>Recess</u>	<u>Cycle</u>			
		<u>1st</u>	<u>5th</u>	<u>10th</u>	<u>15th</u>
1	Hexagon	OK	OK	OK	OK
2	"	"	"	"	"
3	"	"	"	"	"
4	"	"	"	"	"
5	"	"	"	"	"
1	Square	OK	OK	OK	OK
2	"	"	"	"	"
3	"	"	"	"	"
4	"	"	"	"	"
5	"	"	"	"	"
1	Double Square	OK	OK	OK	OK
2	"	"	"	"	"
3	"	"	"	"	"
4	"	"	"	"	"
5	"	"	"	"	"

Notes: 1. OK means screw was reusable after tightening to 100,000 psi load. See Square Drive Evaluation in text.

TABLE V

Ultimate Torque vs. Driver-Recess Clearance
(Maximum engagement of 0.225", Square cut end Drivers used)

<u>No.</u>	<u>Recess</u>	<u>Clearance, in.</u>	<u>Ultimate Torque, in.-lb.</u>	<u>Failure Mode</u>
1	Hexagon	.002	2900	Thread
2	"	.005	2900	"
3	"	.010	2900	"
4	"	.015	2900	"
5	"	.020	2900	"
6	"	.025	2900	Recess
1	Square	.002	2900	Thread
2	"	.005	2900	"
3	"	.010	2900	"
4	"	.015	2900	"
5	"	.020	2900	"
6	"	.025	2900	"
7	"	.030	2900	"
8	"	.035	2900	"
9	"	.040	2900	"
10	"	.045	2900	Recess
1	Double Square	.005	2900	Thread
2	"	.010	2900	"
3	"	.015	2900	"
4	"	.020	2900	"
5	"	.025	2900	"
6	"	.030	2900	"
7	"	.035	2900	Recess

TABLE VI

Ultimate Torque vs. Driver Engagement
for Socket Head Cap Screw Test
Parts with .002" Driver-Recess Clearance

No.	Recess	Clearance, in.	Ultimate Torque, in.-lbs.	Failure Mode
1	Hexagon	.200	2900	Thread
2	"	.200	3000	"
3	"	.200	3000	"
1	Hexagon	.175	2700	Recess
2	"	.175	2900	"
3	"	.175	2800	"
1	Hexagon	.100	1650	Recess
2	"	.100	1500	"
3	"	.100	1500	"
1	Hexagon	.050	550	Recess
2	"	.050	750	"
3	"	.050	800	"
1	Square	.200	2900	Thread
2	"	.200	2900	"
3	"	.200	3000	"
1	Square	.175	3000	Thread
2	"	.175	2900	"
3	"	.175	2800	"
1	Square	.100	2100	Recess
2	"	.100	1800	"
3	"	.100	2100	"
1	Square	.050	1125	Recess
2	"	.050	1200	"
3	"	.050	1050	"
1	Double Square	.200	3000	Thread
2	"	.200	3000	"
3	"	.200	2900	"
1	Double Square	.175	2800	Recess
2	"	.175	2800	"
3	"	.175	2900	"
1	Double Square	.100	1950	Recess
2	"	.100	1650	"
3	"	.100	1400	"
1	Double Square	.050	600	Recess
2	"	.050	750	"
3	"	.050	750	"

TABLE VII

Ultimate Torque vs. Driver Engagement
for Socket Head Cap Screw Test Parts
with .025 Driver-Recess Clearance

No.	Recess	Engagement, in.	Ultimate Torque, in.-lbs.	Failure Mode
1	Hexagon	.200	2900	Recess
2	"	.200	2900	"
3	"	.200	2900	"
1	Hexagon	.175	2600	Recess
2	"	.175	2600	"
3	"	.175	2600	"
1	Hexagon	.100	1250	Recess
2	"	.100	850	"
3	"	.100	1050	"
1	Hexagon	.050	450	Recess
2	"	.050	375	"
3	"	.050	415	"
1	Square	.200	3000	Thread
2	"	.200	3000	"
3	"	.200	3000	"
1	Square	.175	3000	Thread
2	"	.175	3000	"
3	"	.175	3000	"
1	Square	.100	2100	Recess
2	"	.100	1950	"
3	"	.100	1650	"
1	Square	.050	750	Recess
2	"	.050	750	"
3	"	.050	750	"
1	Double Square	.200	3000	Thread
2	"	.200	3000	"
3	"	.200	3000	"
1	Double Square	.175	3000	Recess
2	"	.175	3000	Thread
3	"	.175	3000	Recess
1	Double Square	.100	1950	Recess
2	"	.100	1350	"
3	"	.100	1350	"
1	Double Square	.050	600	Recess
2	"	.050	450	"
3	"	.050	575	"

TABLE VIII

Low Temperature Coatings

1. Cyanide cadmium (0.8-1.2 mil) + dichromate conversion coating.
2. Cyanide zinc (0.3-0.5 mil) + cyanide cadmium (0.5-0.7 mil) + dichromate conversion coating.
3. Sulfamate nickel (0.4-0.6 mil) + cyanide cadmium (0.4-0.6 mil) + dichromate conversion coating.

TABLE IX

Low Temperature Exposure Conditions

Daily

1. Heat, 1 hour with cycle consisting of: hot air blast (400°F), duration 15 seconds; marine atmosphere 2 minutes, 45 seconds. Twenty cycles per hour.
2. Acidified seawater spray - 5 minutes (8% by wt. sulfurous acid).
3. Seawater immersion - 2 hours.
4. Marine atmosphere - 20 hours, 55 minutes.

Weekly

1. Using paint brush, all samples wet down with the following:
 - a. lube oil (automotive grade)
 - b. hydraulic fluid (catapult) - MIL-H-22072A
 - c. aircraft cleaning solution - 50% MIL-C-43616, 50% MIL-C- 25679
2. Scrub down with detergent mixture - 5% detergent, Type II, 95% JP-5. Simulates procedures described in NAVSHIPS Technical Manual, Chapter 9140, 22 June 66, "Cleaning Method A".

Continue cycle for 9 months.

TABLE X

High Temperature Coatings

1. Sulfamate nickel (0.6-0.8 mil) + cyanide cadmium (0.3-0.4 mil) + dichromate conversion coating + diffusion at 630°F for 1 hour.
2. Sulfamate nickel (0.8-1.2 mil).
3. Alseal 500* (0.8-1.2 mil), cured at 350°F for 30 minutes, glass bead blasted.

* A proprietary coating of Coatings for Industry, Philadelphia, Pa.

TABLE XI

High Temperature Exposure Conditions

1. Specimens mounted in test capsules simulating launch valve insulation procedures.
2. Monday - inject 500 ml. solution into each specimen. Solution contains: 85% seawater solution of 2% salinity (deionized water diluted), 5% hydraulic fluid (MIL-H-22072A), 5% aircraft cleaning solution (50% MIL-C-43616, 50% MIL-C-25679), 5% deck washdown solution (5% detergent Type II, 95% JP-5).
3. Monday Noon: Turn on heaters, set to approx. 150°F.
4. Monday 5 P.M.: Increase temperature to approx. 300°F.
5. Tuesday 4 P.M.: Increase temperature to approx. 450°F.
6. Wednesday 4 P.M.: Increase temperature to approx. 600°F.
7. Thursday 4 P.M.: Increase temperature to approx. 700°F.
8. Friday 4 P.M.: Turn off heaters until Monday.
9. Continue cycle for 9 months.

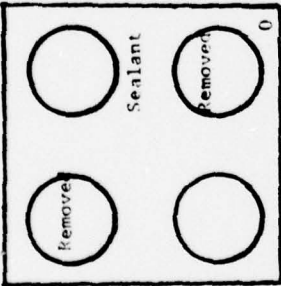
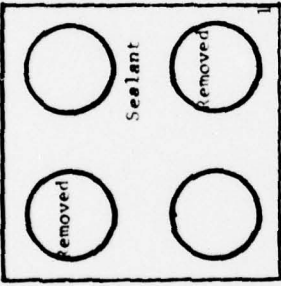
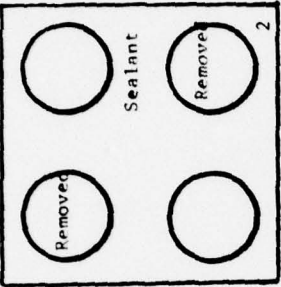
REVISION AND DATE		1		2		3		4		5		6	
Coating		4340 Steel Upper Block, H180 Steel Lower Block											
		1		2		3		4		5		6	
													
		Cyanide Cadmium (.8-1.2 mil) + dichromate conversion ctg.		Cyanide zinc (.3-.5 mil) + cyanide cadmium (.3-.5 mil) + dichromate conversion ctg.		Cyanide nickel (.4-.6 mil) + cyanide cadmium (.4-.6 mil) + dichromate conversion ctg.							
Breakaway Torque		1900		2100		1800		2000		2000		2100	
Prevailing Torque		0		20		10		25		0		40	
Head Recess		Lt. Brown		Wh, Lt. Btn. Prod.		Wh, Corr. Prod.		Lt. Gray		Lt. Brown		Dk. Gray	
Top of Head		Wh, Corr. Prod.		Dk. Gray		Dk. Gray		Lt. Gray		Rusty		Rusty, Dr. Gray	
Side of Head		Wh, Corr. Prod.		Wh, Lt. Btn. Prod.		Dk. Gray		Lt. Gray		Rusty		Sl. Rusty	
Underhead		Clean		Clean		Clean		Clean		Dk. Gray, Rusty		Clean	
Fillet		Clean		Clean		Clean		Clean		Gray		Clean	
Threads		Sl. Corrosion		Clean		Corroded		Clean		Gray, Sl. Rust		Clean	
Point		Rusty		Rusty		Rusty		Rusty		Rusty		Lt. Black	
Block		Rusty		Rusty		Rusty		Rusty		Rusty		Rusty	

TABLE XII

Observations after 3 month exposure at
Ocean City Research Corp.
Low Temperature

TOLEANCE
UNLESS SPECIFIED

FRACT.
DEC.
ANGLES
SURF. FIN.

SPS LABORATORIES

STANDARD PRESSED STEEL CO., JENKINTOWN, PA., 19034
SCALE
DRAWN BY
DATE
NO. PROD. DWG. FINISH
ASSY. TNG. NO.

U.S. Government Printing Office: 1976-663-912/0000 D-1

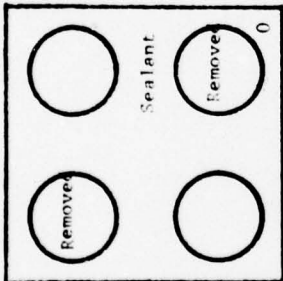
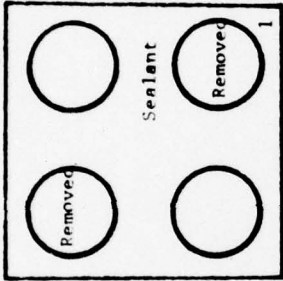
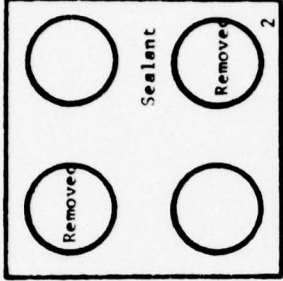
Coating	1		2		3		4		5		6	
	4340 Steel Upper Block,		HV80 Steel Lower Block,									
	1		2		3		4		5		6	
												
	Cyanide Cadmium (.8-1.2 mil) + dichromate conversion ctg.		Cyanide zinc (.3-.5 mil) + cyanide cadmium (.3-.5 mil) + dichromate conversion ctg.		Cyanide zinc (.3-.5 mil) + cyanide cadmium (.4-.6 mil) + dichromate conversion ctg.							
Breakaway Torque	2800	2400	2200	2400	2700	3600	in. lb.	25	in. lb.			
Prevailing Torque	20	10	85	20	80	25						
Head Recess	Rusty	Rusty	Rusty	Rusty	Sl. Rusty	Sl. Rusty						
Top of Head	Rusty	Rusty	Rusty	Rusty	Stained	Stained						
Side of Head	Rusty	Rusty	Rusty	Rusty	Stained	Stained						
Underhead	Clean	Clean	Clean	Clean	Clean	Clean						
Flillet	Clean	Clean	Clean	Clean	Clean	Clean						
Threads	Sl. Corroded	Clean	Corroded	Clean	Sl. Corroded	Clean						
Point	Rusty	Rusty	Rusty	Sl. Rusty	Stained	Stained						
Block	Rusty	Rusty	Mod. Rusty	Mod. Rusty	Heavy Rust	Heavy Rust						

TABLE XIV

Observations after 6 month exposure at
Ocean City Research Corp.

Low Temperature

SPS LABORATORIES

STANDARD PRESSED STEEL CO., JENKINTOWN, PA., 19048

HEAT TREAT

NO. ASSY

REF. DWG.

DATE

SCALE

DRAWN BY

DATE

NO. PARTS

LIST

NO. DWG.

NO.

U.S. Government Printing Office: 1976-665-613/0025 2-1

U.S. Government Printing Office: 1976-663-612/6025 2-1

TABLE XVIII

High Temperature Exposure Results - Initial 4 1/2 Months

	<u>Fastener Coating System</u>	<u>Block</u>	<u>Fasteners</u>
1.	Diffused nickel-cadmium	Corroded	Rusty
2.	Sulfamate nickel	Corroded	Rusty
3.	Alseal 500	Corroded	Rusty

TABLE XIX

High Temperature Exposure Results - SECOND 4 1/2 Months

<u>Fastener Coating System</u>	<u>Block</u>	<u>Fasteners</u>
1. 0.7 mil nickel	Severely Corroded	Clean
2. 1.0 mil nickel	Severely Corroded	Clean
3. 0.7 mil nickel + TBS757A sealant	Corroded	Clean
4. 1.0 mil nickel + TBS757A sealant	Corroded	Clean
5. Inconel 718	Slightly Corroded	Clean
6. Inconel 718 + TBS757A sealant	Slightly Corroded	Clean
7. Inconel 718 + SermeTel 385	Severely Corroded	Clean
8. Inconel 718 + Never-Seez	Severely Corroded	Clean

TABLE XX

Hole Diameter Increase (+) or Decrease (-),
Inches After 4 1/2 Month Exposure
Hole

Block			A	B	C	D
1	Front	T	+0.0008	-.0002	+0.0018	+0.0038
		C	+0.0018	-.0002	+0.0010	+0.0004
		B	+0.0011	-.0004	+0.0017	-.0012
	Rear	T	-.0010	-.0013	-.0001	+0.0003
		C	-.0002	+0.0005	+0.0012	+0.0008
		B	+0.0024	+0.0004	+0.0018	+0.0002
2	Front	T	+0.0090	+0.0024	+0.0058	+0.0104
		C	+0.0077	-.0054	+0.0089	-.0097
		B	+0.0078	-.0051	+0.0062	-.0108
	Rear	T	+0.0082	-.0031	+0.0064	-.0044
		C	+0.0092	-.0016	+0.0038	-.0052
		B	-.0044	-.0047	-.0045	-.0074
3	Front	T	.0000	+0.0016	-.0002	-.0003
		C	.0000	+0.0010	-.0012	-.0003
		B	+0.0004	+0.0024	-.0026	+0.0012
	Rear	T	+0.0006	+0.0041	+0.0034	+0.0028
		C	+0.0026	+0.0052	+0.0051	+0.0048
		B	+0.0014	+0.0050	-.0007	+0.0058
4	Front	T	-.0070	-.0051	-.0065	-.0077
		C	-.0060	-.0014	+0.0025	-.0049
		B	-.0025	+0.0012	-.0133	-.0186
	Rear	T	+0.0089	+0.0088	+0.0085	+0.0086
		C	+0.0053	+0.0075	+0.0088	+0.0037
		B	+0.0040	+0.0073	-.0003	+0.0024

Note * Instrument employed was Brown & Sharpe Inermike 281 A00029-08
0.800"-1.000" capacity

T = Top

C = Center

B = Bottom

Low Temperature Long Term Exposure

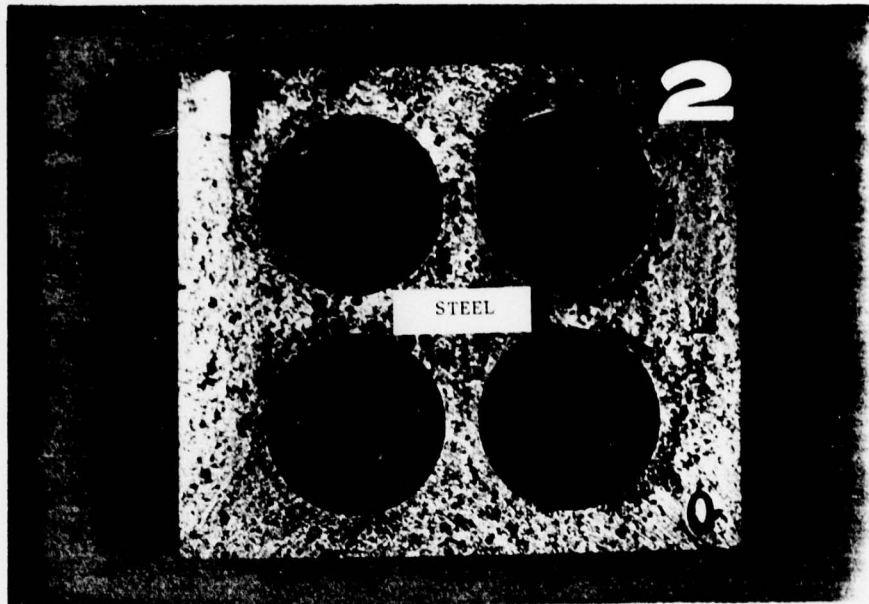


Photo 1. 9 month exposure of steel block at Ocean City produced rusting when cadmium plated screws were used in it. See Table XVI.

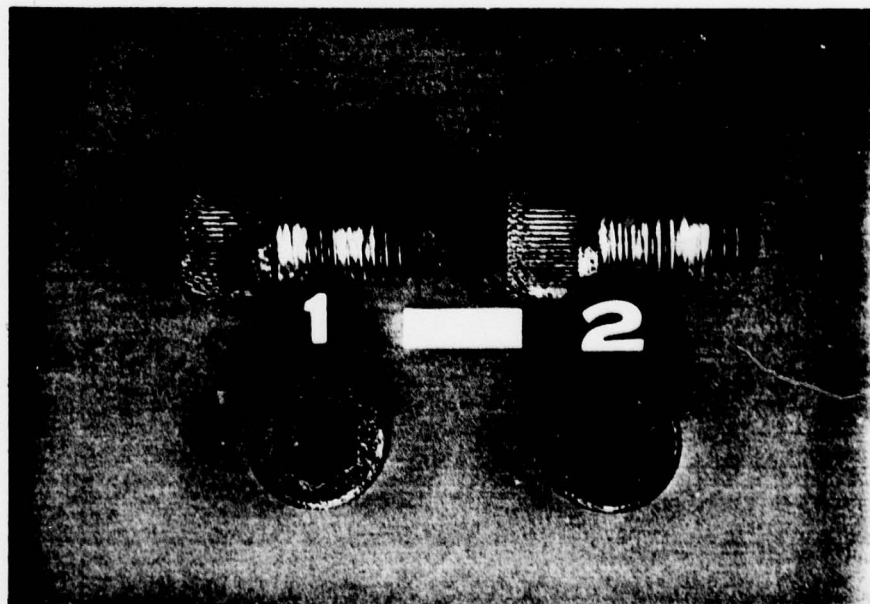


Photo 2. Thick (0.8-1.2 mil) cadmium plating did not survive a 9 month exposure at Ocean City. See Table XVI.

Low Temperature Long Term Exposure

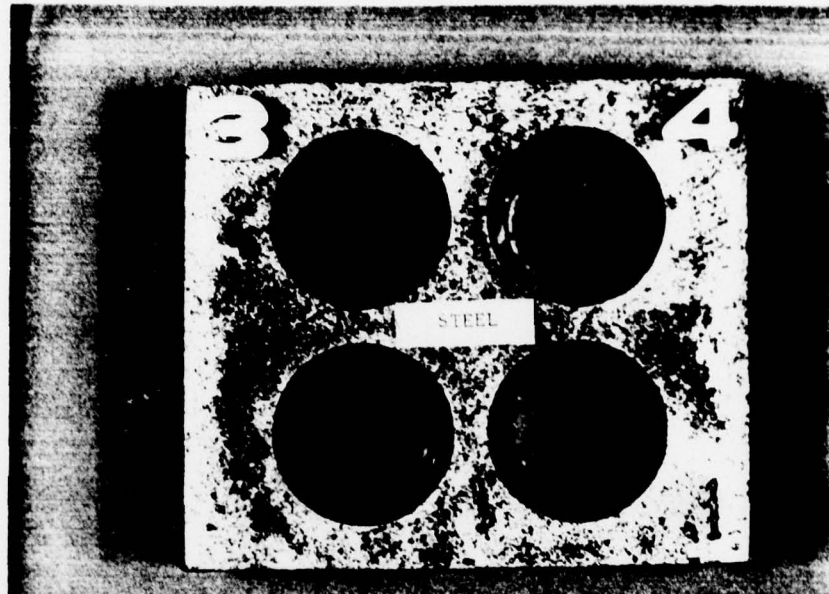


Photo 3. 9 month exposure of steel block at Ocean City produced rusting when zinc overcoated with cadmium plated screws were used in it. See Table XVI.

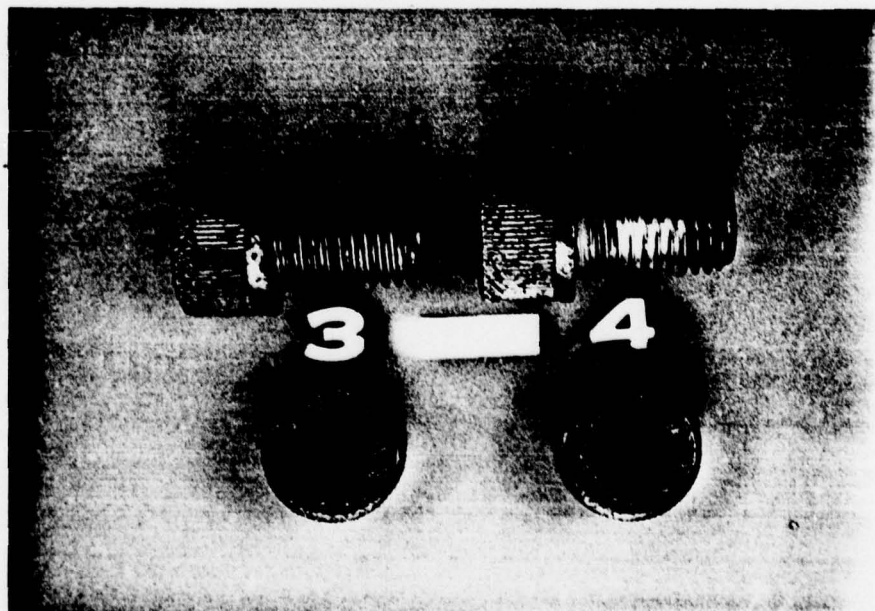


Photo 4. Thick zinc (0.3-0.5 mil) overcoated with cadmium (0.5-0.7 mil) plating did not survive a 9 month exposure at Ocean City. See Table XVI.

Low Temperature Long Term Exposure

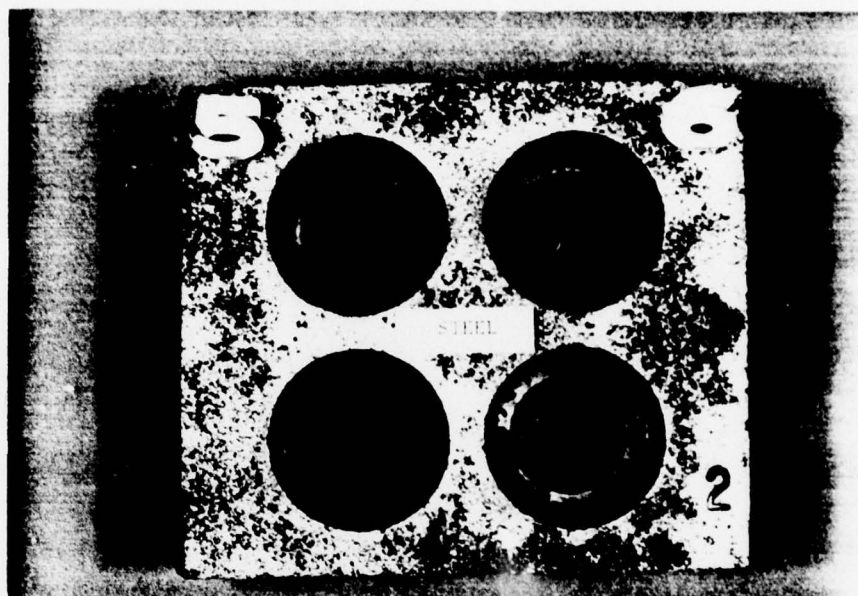


Photo 5. 9 month exposure of steel block at Ocean City produced rusting when nickel overcoated with cadmium plated screws were used in it. See Table XVI.

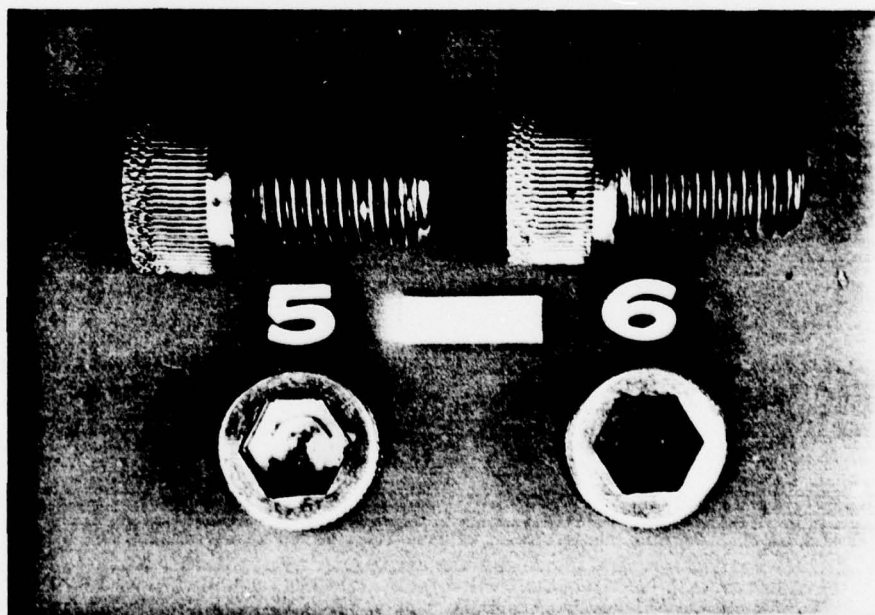


Photo 6. Thick nickel (0.4-0.6 mil) overcoated with cadmium (0.4-0.6 mil) plating survived a 9 month exposure at Ocean City. The cadmium was consumed but most of the nickel remained intact. See Table XVI.

Low Temperature Long Term Exposure

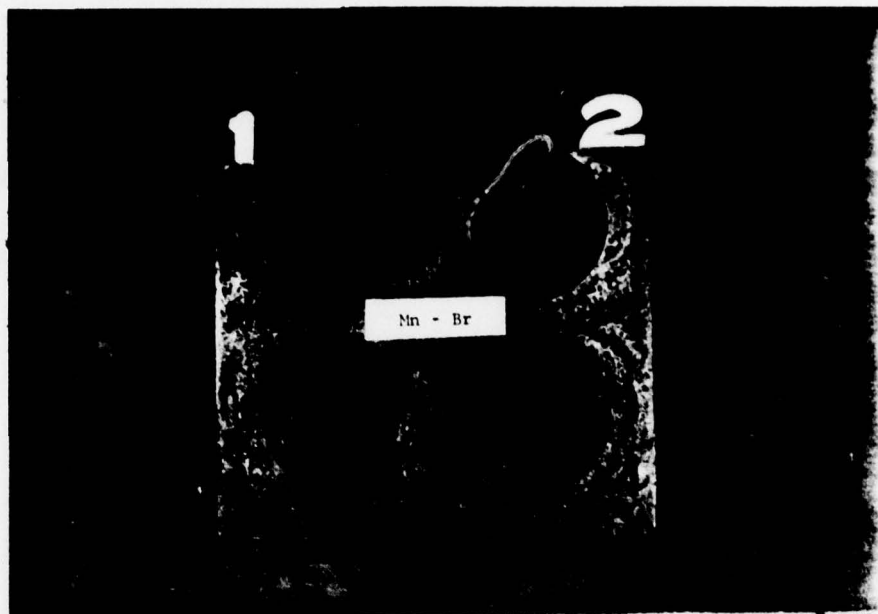


Photo 7. 9 month exposure of manganese bronze block at Ocean City produced staining when cadmium plated screws were used in it. See Table XVII.

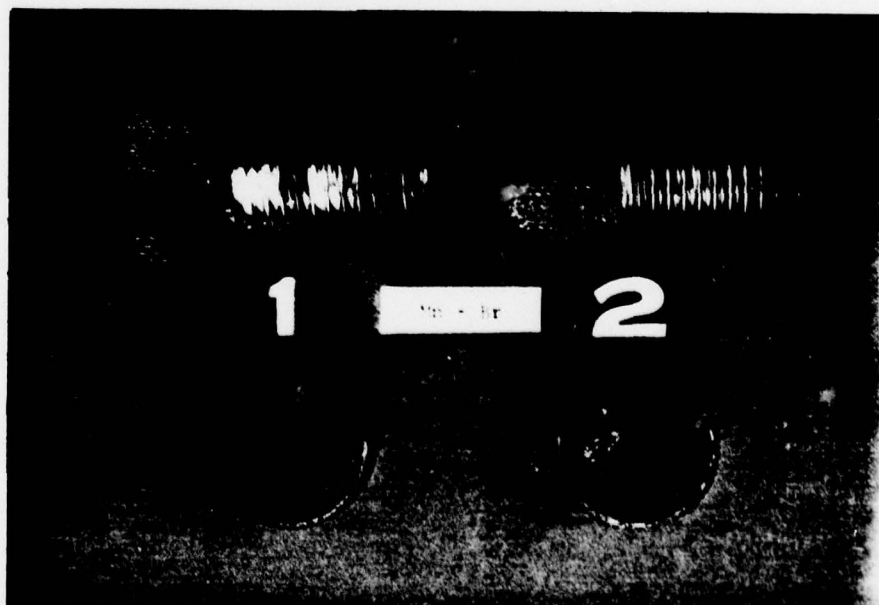


Photo 8. Thick (0.8-1.2 mil) cadmium plating did not survive a 9 month exposure at Ocean City. See Table XVII.

Low Temperature Long Term Exposure

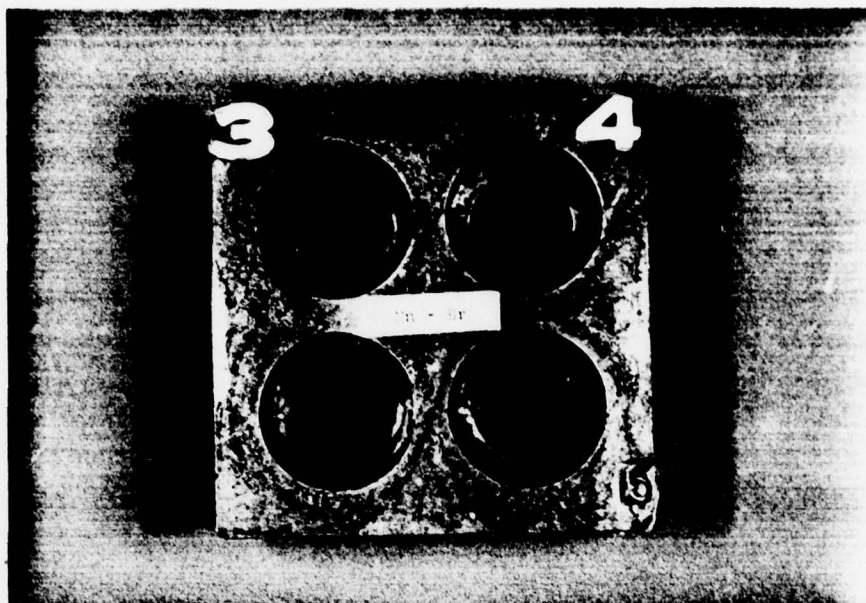


Photo 9. 9 month exposure of manganese bronze block at Ocean City produced staining when zinc overcoated with cadmium plated screws were used in it. See Table XVII.

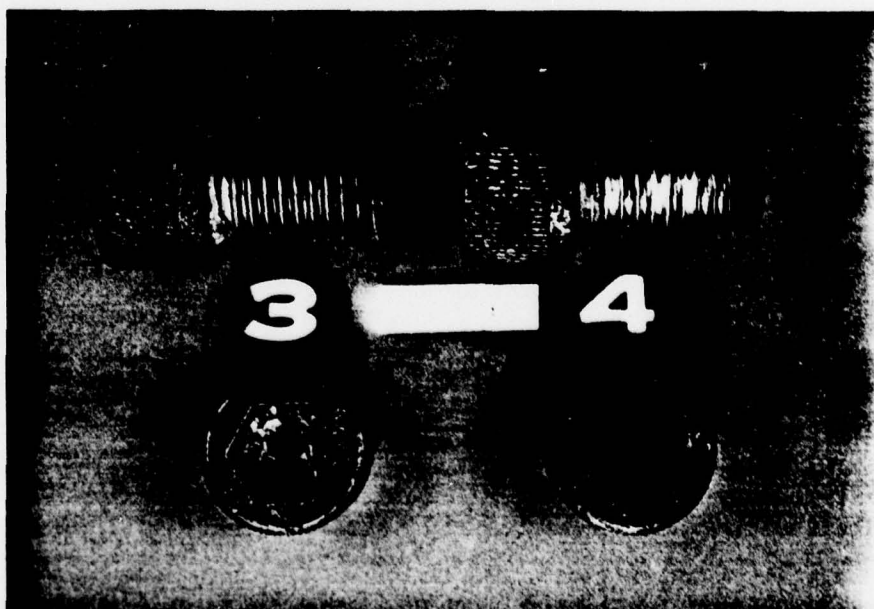


Photo 10. Thick zinc (0.3-0.5 mil) overcoated with cadmium (0.5-0.7 mil) plating did not survive a 9 month exposure at Ocean City. See Table XVII.

Low Temperature Long Term Exposure

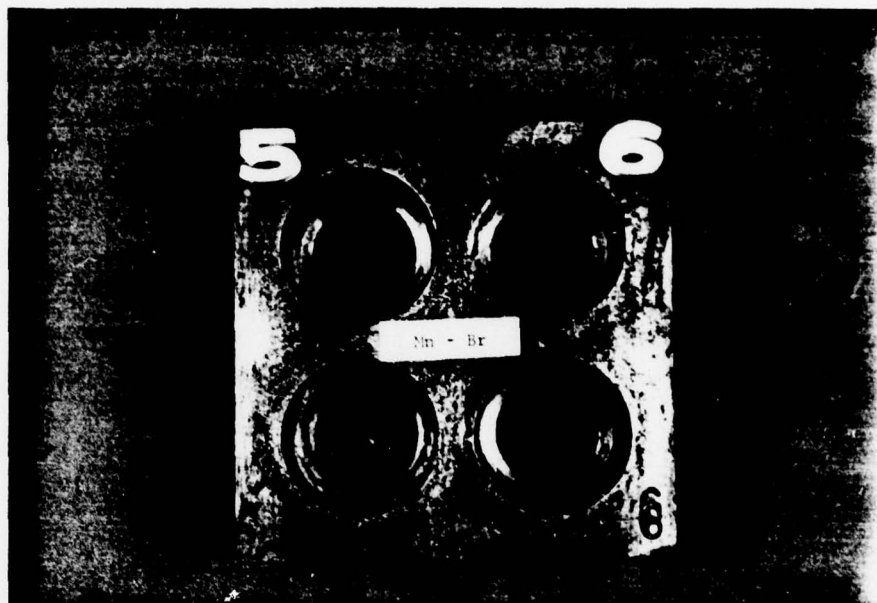


Photo 11. 9 month exposure of manganese bronze block at Ocean City produced staining when nickel overcoated with cadmium plated screws were used in it. See Table XVII.

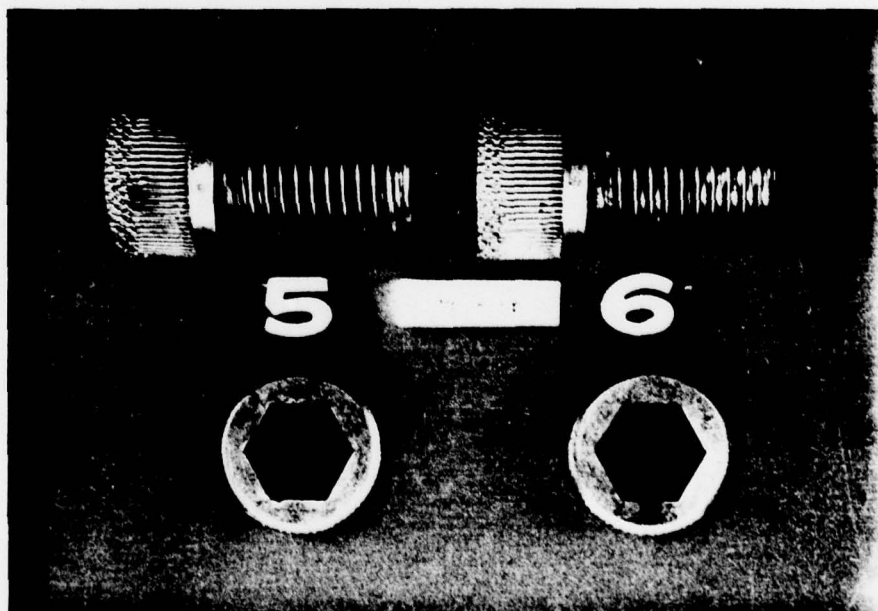


Photo 12. Thick nickel (0.4-0.6 mil) overcoated with cadmium (0.4-0.6 mil) plating survived a 9 month exposure at Ocean City. The cadmium was consumed but most of the nickel remained intact. See Table XVII.

High Temperature Long Term Exposure

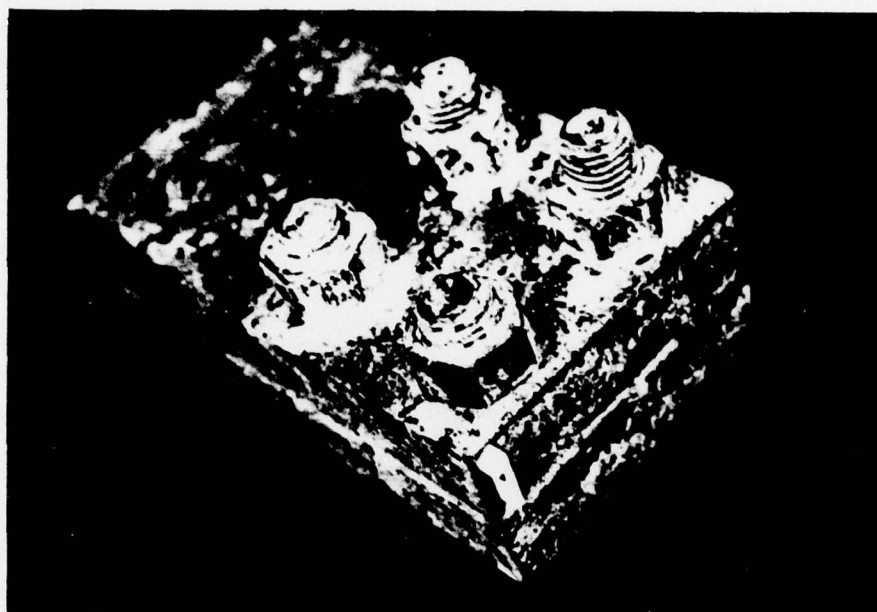


Photo 13. 4 1/2 month exposure at Ocean City produced extensive corrosion products. Steel studs and nuts coated with 0.7 or 1.0 mil electroplated sulfamate nickel. See Table XIX.



Photo 14. 4 1/2 month exposure at Ocean City produced extensive corrosion products. Steel studs and nuts coated with 0.7 or 1.0 mil nickel and silicone sealant. See Table XIX.

High Temperature Long Term Exposure

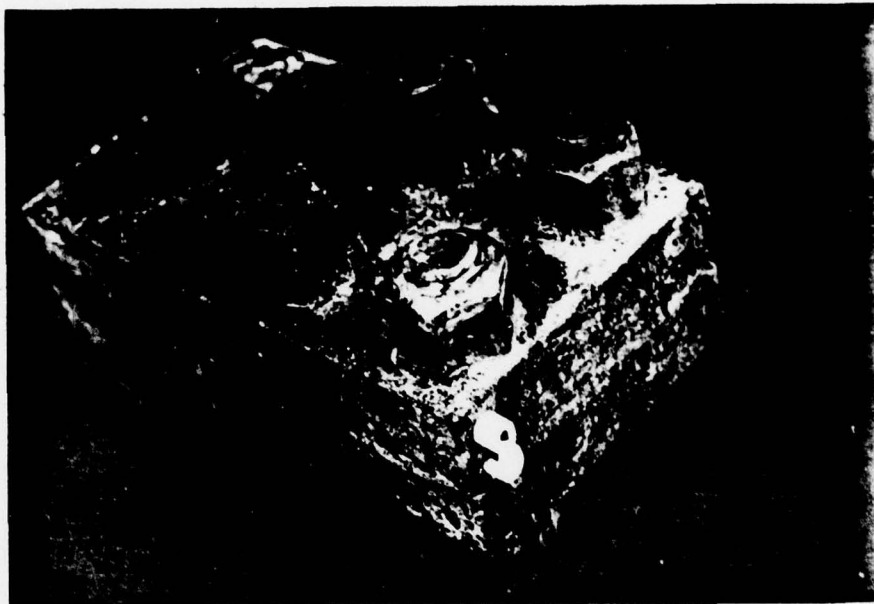


Photo 15. 4 1/2 month exposure at Ocean City produced extensive corrosion products. Inconel 718 studs and nuts used with or without silicone sealant. See Table XIX.

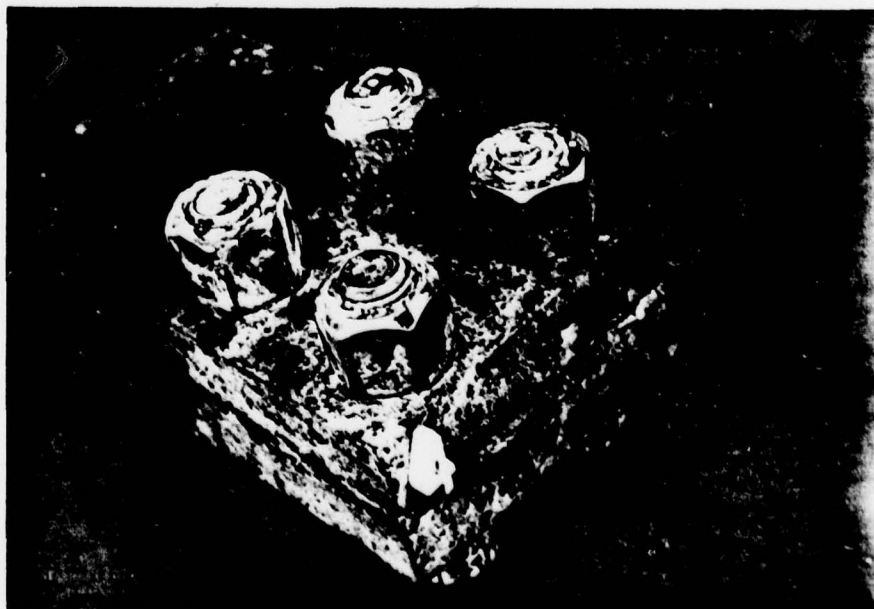


Photo 16. 4 1/2 month exposure at Ocean City produced extensive corrosion products. Inconel 718 studs and nuts used with a sacrificial coating or an anti-seize compound. See Table XIX.

High Temperature Long Term Exposure

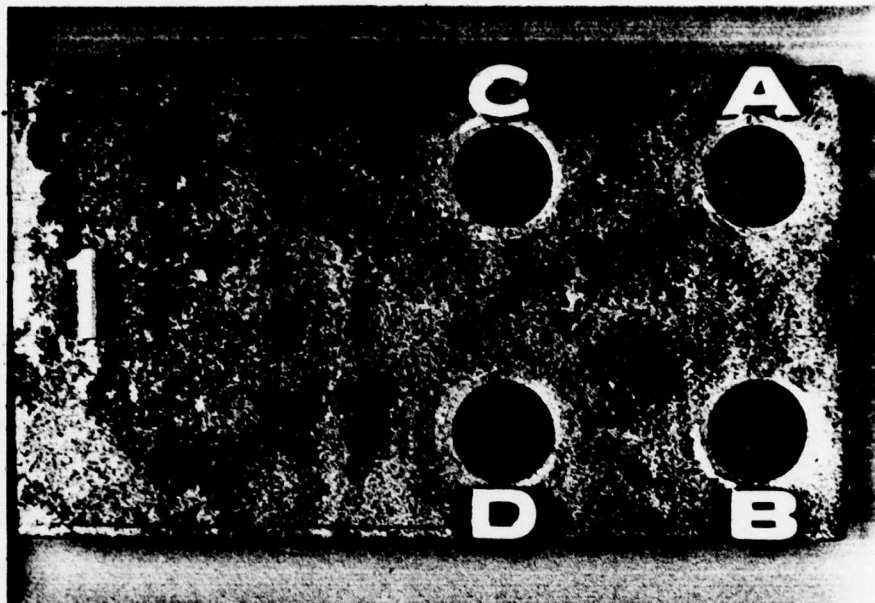


Photo 17. 4 1/2 month exposure at Ocean City consumed almost all of the Metco 120 aluminum coating. Studs and nuts had 0.7 mil (A & C) or 1.0 mil (B & D) electroplated nickel.

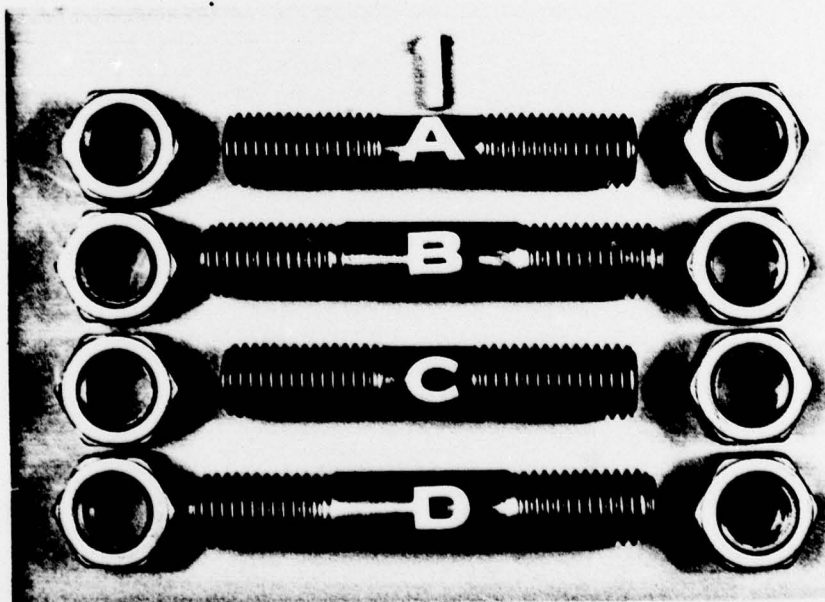


Photo 18. 4 1/2 month exposure at Ocean City did not cause any corrosion of 0.7 mil (A & C) or 1.0 mil (B & D) electroplated nickel.

High Temperature Long Term Exposure

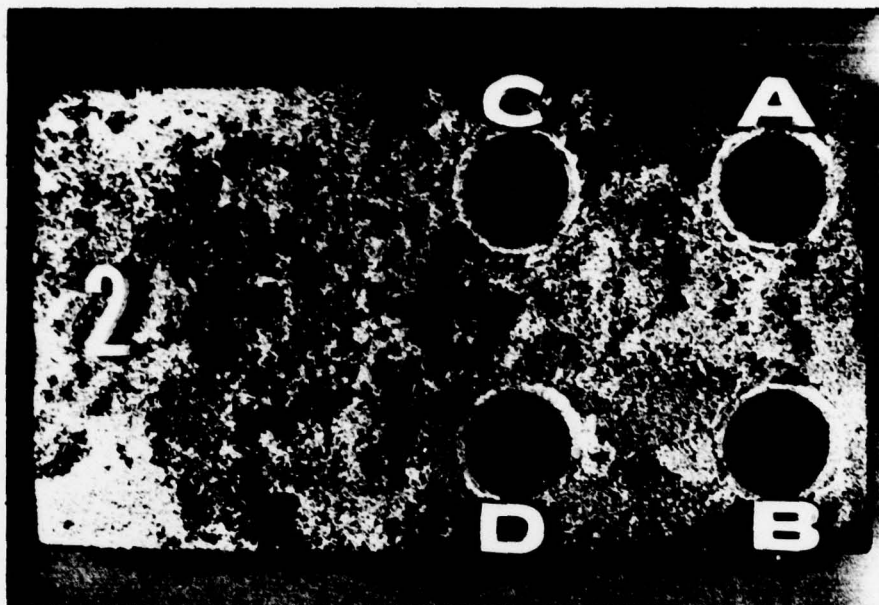


Photo 19. 4 1/2 month exposure at Ocean City consumed about 60% of the Metco 120 aluminum coating. Studs and nuts had 0.7 mil (A & C) or 1.0 mil (B & D) electroplated nickel and a high temperature silicone sealant.

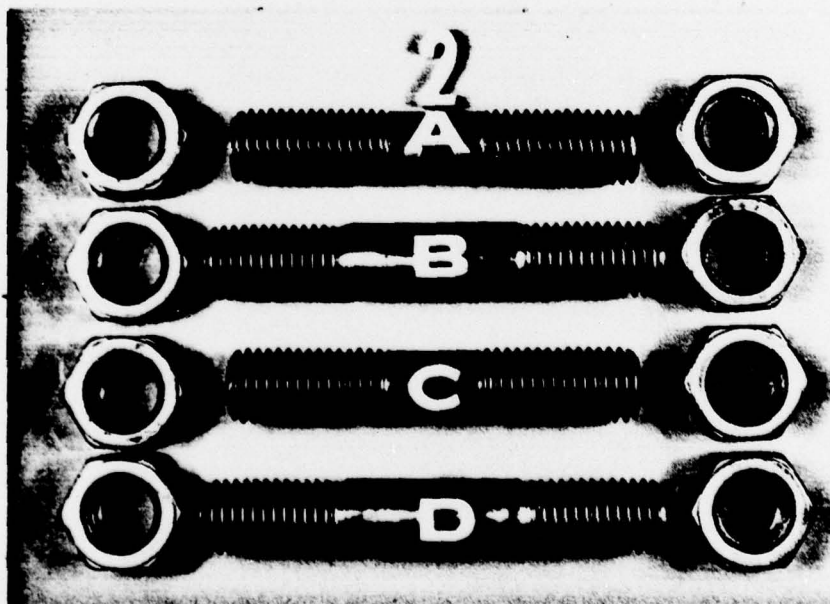


Photo 20. 4 1/2 month exposure at Ocean City did not cause any corrosion of 0.7 mil (A & C) or 1.0 mil (B & D) electroplated nickel. A high temperature silicone sealant was employed also.

High Temperature Long Term Exposure

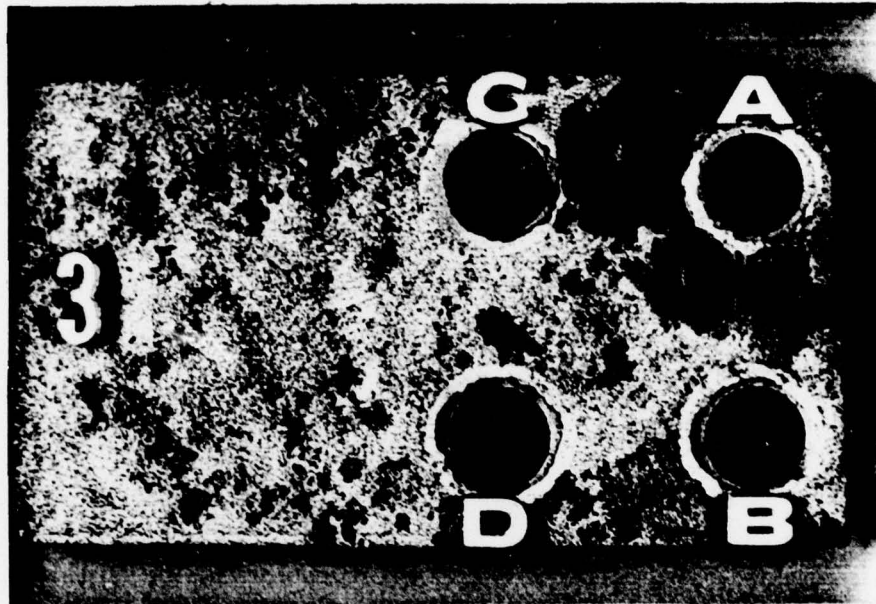


Photo 21. 4 1/2 month exposure at Ocean City consumed about 20% of the Metco aluminum coating. Studs and nuts were Inconel 718, bare (A & C) or smeared (B & D) with a high temperature silicone sealant.

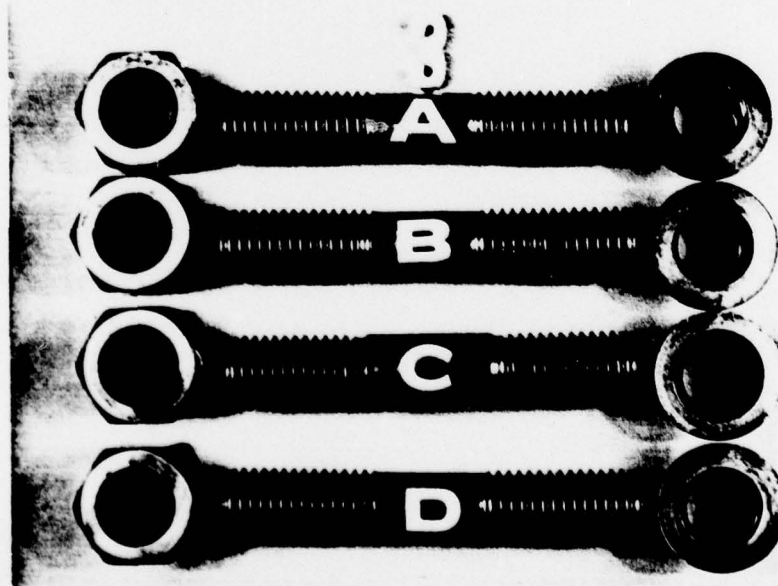


Photo 22. 4 1/2 month exposure at Ocean City did not cause any corrosion of Inconel 718. A high temperature silicone sealant was employed on B & D.

High Temperature Long Term Exposure

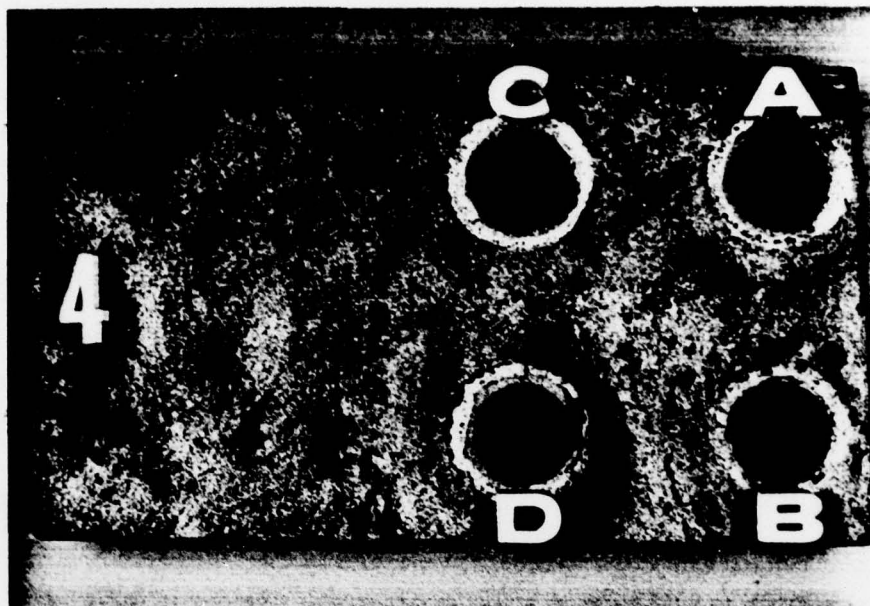


Photo 23. 4 1/2 month exposure at Ocean City consumed almost all of the Metco 120 aluminum coating. Studs and nuts were Inconel 718 coated with SermeTel 385 (A & C) or Never-Seez (B & D).

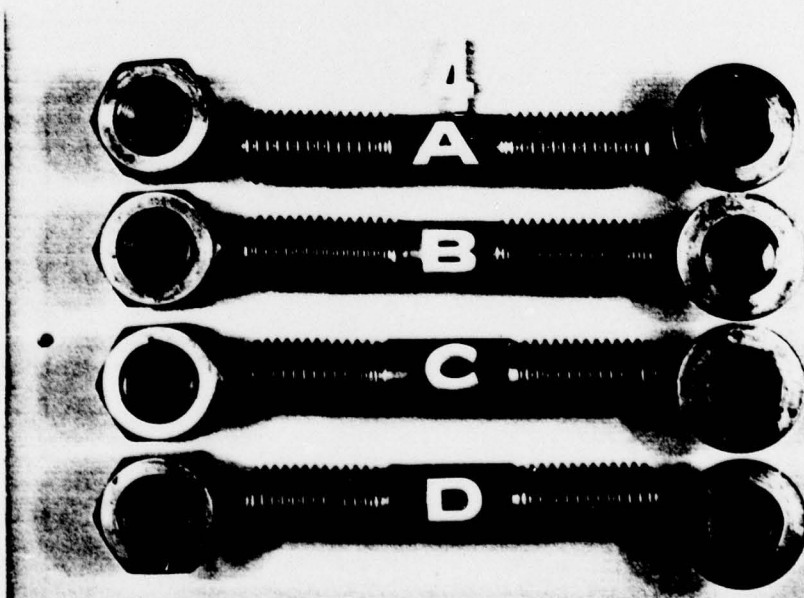


Photo 24. 4 1/2 month exposure at Ocean City did not cause any corrosion of Inconel 718. SermeTel 385 was employed on A & C while Never-Seez was used on B & D.